

BASIC SEWAGE TREATMENT OPERATION

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Ontario

Ministry
of the
Environment

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BASIC SEWAGE TREATMENT OPERATION

First edition November, 1972
Second edition February, 1973
Third edition January, 1974
Second printing May, 1974
Third printing April, 1975
Fourth edition June, 1976
Fourth edition (Rev.) November, 1978

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INTRODUCTION

The *Basic Sewage Treatment Operation* course based on this manual covers five days at the Ministry of the Environment training facilities. The course consists of lecture-discussions and hands-on training in sewage treatment plant operations.

The principal objective of the course is to introduce the operator to the fundamentals of sewage plant operation. The lesson objectives are clearly indicated at the beginning of each topic, and tell the operator exactly what he should know or do after having covered that topic. In order to successfully complete this course, an overall average of 70% is required.

This is a working course in which each person will be expected to take an active part in subject discussions and to acquire as much practical knowledge as possible from the lectures and from the demonstrations presented during the course.

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SUBJECT: 1

SEWAGE TREATMENT OPERATION

TOPIC: 1

INTRODUCTION TO
SEWAGE TREATMENT

OBJECTIVES:

The trainee will be able to:

1. Describe, using a diagram, the typical sewage treatment plant.
2. Identify three sources of municipal sewage.
3. Discuss in general terms the physical, chemical and bacteriological characteristics of sewage.
4. Recall the approximate percent BOD and suspended solids normally removed in
 - a) the primary treatment plant,
 - b) the secondary treatment plant.
5. Define terms commonly used in sewage treatment operations.
6. Explain the importance of nutrients in the operation of sewage treatment plants.
7. Discuss the effects of inadequately treated plant effluent on receiving waters.

SEWAGE CHARACTERISTICS

GENERAL

The adequate treatment of sewage is one of the most important responsibilities of municipalities.

In the 19th Century, several large European cities built closed conduits or pipes for collecting human wastes when the use of streets as open sewers created intolerable living conditions. The discharge of these wastes to nearby rivers and streams soon produced obnoxious odours and ugly conditions.

At about the same time, epidemics were traced to water supplies originating from these rivers and streams. It was discovered that bacteria in the sewage caused diseases such as typhoid fever, dysentery, and cholera. The treatment of sewage thus became a necessity.

Sewage contains countless numbers of living organisms, most of them too small to be visible without the aid of a microscope. They are a natural living part of the organic matter found in sewage and they are important because they are one of the reasons for the success of our present treatment processes. Generally, the microscopic living organisms in sewage are *bacteria* and other more complex higher forms of organisms.

An intensive study of bacteria has shown that only a small number of them are disease carriers. These and other bacteria are destroyed in nature through the activities of higher forms of microbial life. Together, the organisms play a major role in *degrading* or *breaking down* organic matter (dead plants and animals and their wastes). By harnessing these organisms under ideal conditions, as in sewage treatment plants, the breaking down of organic wastes can be speeded up and controlled.

SOURCES OF SEWAGE

In nature, sewage is present as the waste by-product of human and animal life. Man has added to this the waste products of industrial and commercial activity. So the composition of sewage varies widely in both quantity and quality.

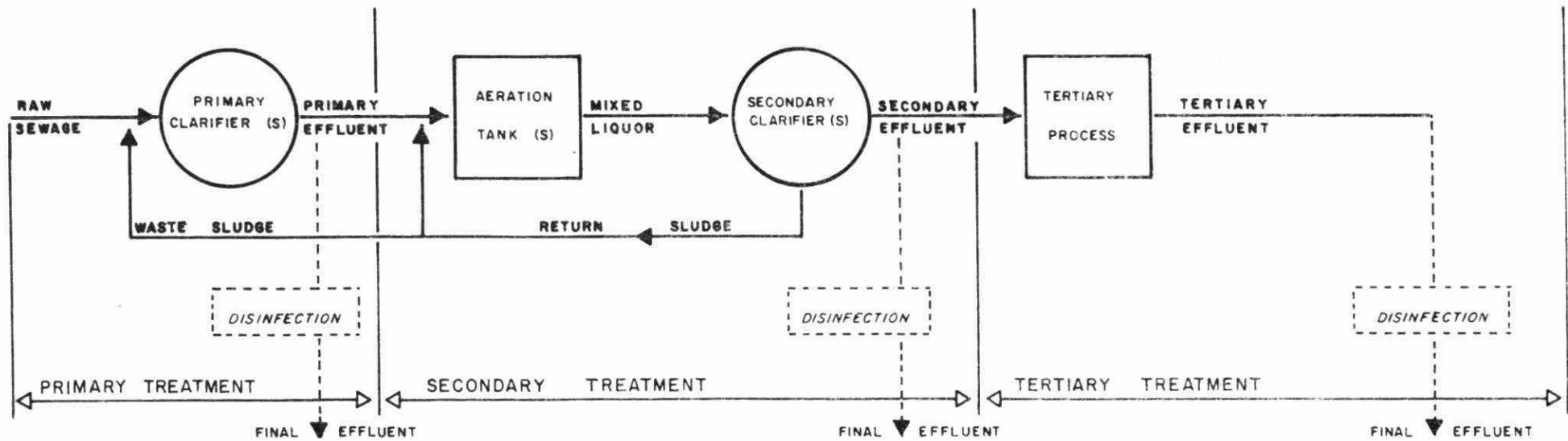
Domestic wastes are those that originate in the bathroom, the kitchen and the laundry room. Once these reach the municipal sewer and combine with any *industrial* and/or *commercial wastes*, they are called *sanitary* or *raw sewage*. Normal sanitary sewage is easily treated in a properly designed sewage treatment plant. Industrial and commercial wastes contained in the sanitary sewage may sometimes be unacceptable for treatment in a municipal sewage plant. In these cases, they must be pre-tested before they are discharged into the sewers.

Figure 1-1 is a schematic diagram of a typical conventional activated sludge plant. *Primary treatment* is used to remove settleable solids from the raw sewage entering the primary clarifiers. The liquid leaving these tanks, called *primary effluent*, may then be disinfected and discharged to a watercourse or directed to aeration tanks, the first stage of *secondary (biological) treatment*. The organic matter in the primary effluent serves as food for large numbers of organisms (*activated sludge*) in these tanks. With adequate oxygen, the organisms use the food for energy and reproduction.

The contents of the aeration tanks, called *mixed liquor*, then flow into secondary clarifiers where the organisms are allowed to settle and the clear liquid (*secondary effluent*) is either disinfected and discharged, or directed to a *tertiary treatment* process. The settled activated sludge is returned to the aeration tank for re-use, with waste sludge directed to the primary clarifiers. Tertiary treatment further removes solids and organic matter, using processes such as *lagooning*, *filtration*, or chemical treatment and *clarification*.

FIGURE № 1-1

TYPICAL SEWAGE TREATMENT PLANT



REMOVAL OF B.O.D. & S.S.	B. O. D.		SUSPENDED SOLIDS (S.S.)	
	% Removed	Effluent mg/l	% Removed	Effluent mg/l
PRIMARY PLANT	30 - 40	90 - 150	40 - 60	100 - 150
SECONDARY PLANT	95	15	90 - 95	15
TERTIARY PLANT	98	5	98	5

Before being discharged to any stream or waterway, the effluent is always treated with chlorine or some other disinfectant to destroy any remaining disease-causing bacteria. *Regardless of the amount of treatment given the sewage, the liquid leaving the plant is called the final or plant effluent.* Chemicals may be added to the sewage ahead of the primary clarifiers, directly into the aeration tanks, or ahead of the tertiary process in order to remove phosphorus.

QUANTITY OF SEWAGE

In addition to carrying domestic, industrial and commercial wastes, the sanitary sewers may receive large quantities of water from rain and street washings. Water in the ground may also enter sewers through broken and poorly constructed sewer pipes and direct storm drain connections. This is called *infiltration*. Although older sewer systems may collect sanitary sewage and storm water in a single sewer, present policy requires the separate collection of each, since a treatment plant must be designed according to the total flows reaching it. It would be uneconomical to construct a large plant to treat immense quantities of very dilute sewage which only arrive during rainy periods.

The total quantity of sewage reaching the plant is called the *hydraulic load*, varying from hour to hour and day to day. Normally, daily flows will range between 70 and 130 percent of the water consumption. This percentage will rise if the entry of ground and surface water is a major factor. It will go down due to lawn watering, car washing, hydrant flushing and many other domestic and industrial uses from which the used water is not directed to the sanitary sewer system. An average municipality without large industrial sewage contributors will produce approximately 100 gallons of sewage per capita (person) per day (gpcd). Small rural municipalities and major cities will produce approximately 50 and 100 gpcd, respectively. *Solids account for less than 0.1 of 1 percent by weight of the total sewage flow. The remaining 99.9 percent is water, which carries the solids through the sewer pipes.*

QUALITY OF SEWAGE

A treatment plant removes undesirable materials from sewage, making it acceptable for discharge to lakes or streams. *In so doing, the bacteriological, physical, and chemical characteristics of the sewage are changed.* These changes can best be seen by comparing the characteristics of the raw sewage, primary effluent, secondary effluent, and final effluent of a treatment plant.

Bacteriological Characteristics

Fresh raw sewage may normally contain from 10 to 200 million bacteria per 100 millilitres. Some are harmful to humans and others are not. Complete secondary treatment reduces these numbers by 80 to 95 percent, with effluent chlorination increasing the percentage "kill" to 99.9 percent or better. The highest reductions are generally achieved only when the treatment plant is operating efficiently.

Physical Characteristics

The physical characteristics of sewage include *temperature, turbidity, colour and odour.* Table 1-1 compares the physical changes which take place through a typical treatment plant.

TABLE No. 1-1

FLOW	TEMPERATURE	TURBIDITY	COLOUR	ODOUR
Raw Sewage	generally warm	high in solids	milky-grey to black	musty to sulphurous
Primary Effluent	lower temperature	fine nonsettle-able solids	greyish to colourless	musty to sulphurous
Secondary Effluent	lower temperature	no visible solids	clear colourless	fresh

The temperature of raw sewage will vary, depending on the source of water supply for the municipality. However, the resultant raw sewage is always somewhat warmer than the water supply. As the sewage passes through the treatment plant, the temperature decreases. The higher the sewage temperature, the faster the decomposition and the better the settleability.

Raw sewage is highly turbid, containing many different types of solids such as paper, rags, garbage, feces, sand and silt. Primary effluent will contain finely suspended and floating matter which can be removed by biological treatment, to produce a clear, colourless secondary effluent.

The normal milky-grey colour of raw sewage will not be evident if coloured industrial wastes or partially decomposed sewage are involved. Septic or partially decomposed sewage is dark, sometimes black in colour with a sulphurous odour. Normal sewage smells musty but not unpleasant. Primary effluent will be similar to raw sewage except that a large portion of the solids has been removed. The secondary effluent of a properly operated biological treatment plant will be clear and colourless with a fresh odour. Effluent chlorination does not affect temperature, turbidity or colour. It will, however, produce a fresh chlorine odour.

Chemical Characteristics

Chemically, sewage is composed of a great many inorganic and organic solids which are carried in water. The sewage may also contain dissolved gases and living organisms. Inorganic or *fixed* substances are inert and generally will not decay or burn. On the other hand, organic materials will decompose and are sometimes called *volatile matter* since they will burn when heated to high temperature.

Solids

Inorganic and organic substances which can be seen in the sewage are known as *suspended solids*. These are the solids which can be removed from the sewage by physical or mechanical means, such as sedimentation or filtration. Those that are not seen are classified as *dissolved solids*. *Total solids*, as the name implies, include all of the solids contained in sewage.

Inorganic solids consist of sand, silt, clay, the dissolved minerals and salts in community water supplies and any other inert matter contained in wastes discharged to the sewers. *Hard water produces a higher mineral content in the sewage*. Some of the more common minerals and salts found in sewage are sulphates, carbonates, bicarbonates and chlorides of calcium, magnesium, sodium, potassium and iron. These are beneficial to the organisms and not normally troublesome in a sewage treatment process.

Organic solids are generally of animal or vegetable origin. Some synthetic compounds, however, are also organic in nature. All organic matter consists of hydrogen, oxygen and carbon. These substances may be combined with inorganic nitrogen, sulphur or phosphorus. The principle groups formed are called proteins, carbohydrates and fats. These serve as food for bacteria and higher forms of organisms, resulting in decomposition or decay of the organic matter. Decomposition leads to the formation of carbon dioxide, nitrogenous compounds consisting of ammonia, nitrites and nitrates, and sulphurous substances such as hydrogen sulphide gas and various sulphate compounds. These waste products are in turn used by plant and animal life in their growth processes. The cycles of life, death and decay involve carbon, nitrogen and sulphur. These basic elements recycle in our environment where the products of death and decay become the foods for plant and animal life.

Quantities or concentrations of solids, whether inorganic or organic, will differ from hour to hour and from sewage plant to sewage plant. Typical concentrations of solids in a medium strength raw sewage are shown graphically in Figure 1-2. Sewage strength can be defined as the amount of organic material present in the sewage. The successful operation of a biological treatment plant depends, to a great extent, upon this sewage strength because it provides the food for the organisms.

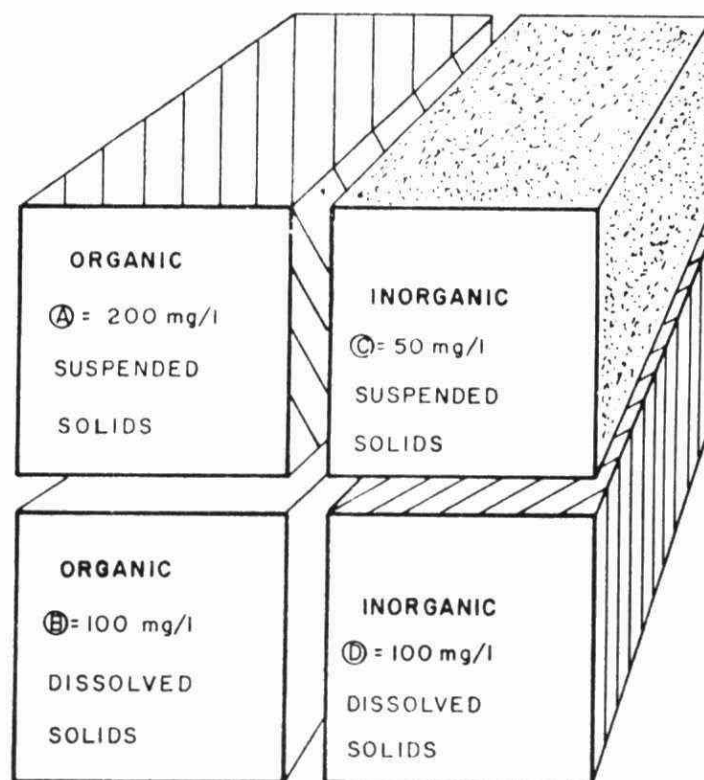
The total solids in a sewage consist of all suspended and dissolved inorganic and organic materials. From Figure 1-2 it can be seen that the concentration of total solids in medium strength sewage is approximately 450 mg/l. This consists of 300 mg/l organic matter in addition to 150 mg/l inorganic matter. The same total solids figure is arrived at by adding the suspended and dissolved solids (shown as 250 mg/l and 200 mg/l respectively).

When storm or ground water finds its way into the sewage, the relationships of these solids may change significantly. Similarly, industrial and commercial wastes may increase the solids content with definite variations in the strength of the sewage. Also, sewage will vary widely in both composition and volume from hour to hour, depending upon changes in community activities. Sewage is likely to be at its maximum strength and flow during the daytime and at its minimum during the night hours. On weekends and holidays, flows and strengths are often reduced due to slower communal activity. Therefore, data on sewage can never be applied equally to all sewages at all times.

A primary sewage treatment plant will normally reduce suspended solids by 40 to 60%. Complete secondary treatment generally will remove 90 to 95% of the suspended solids, producing a final effluent with suspended solids less than 15 mg/l.

FIGURE N° 1-2

COMPOSITION OF SOLIDS IN A MEDIUM STRENGTH RAW SEWAGE



$$\text{TOTAL SOLIDS} = (A) + (B) + (C) + (D) = 200 + 100 + 50 + 100 = 450 \text{ mg/l}$$

$$\text{TOTAL ORGANIC SOLIDS} = (A) + (B) = 200 + 100 = 300 \text{ mg/l}$$

$$\text{TOTAL INORGANIC SOLIDS} = (C) + (D) = 50 + 100 \text{ mg/l}$$

$$\text{TOTAL SUSPENDED SOLIDS} = (A) + (C) = 200 + 50 = 250 \text{ mg/l}$$

$$\text{TOTAL DISSOLVED SOLIDS} = (B) + (D) = 100 + 100 = 200 \text{ mg/l}$$

Biochemical Oxygen Demand (BOD)

The standard for determining the organic strength of sewage is called the *Biochemical Oxygen Demand* or *BOD*. This is simply a measure of the oxygen used in decomposing organic matter. Normally, the test is carried out in the laboratory at a temperature of 20°C over a period of five days with the result being reported in ppm or mg/l 5-day BOD (BOD_5).

Raw sanitary sewage will normally have a BOD_5 ranging between 150 mg/l and 250 mg/l. Industrial and commercial wastes will affect this, however. A primary sewage treatment plant will normally reduce BOD by 30-40%. Complete secondary treatment generally will remove 95% of the BOD, producing a final effluent with a BOD less than 15 mg/l.

Dissolved Gases

Sewage contains small and varying concentrations of dissolved gases. Among the most important of these is oxygen, present in the original water supply and also dissolved from air in contact with the surface of flowing sewage. In addition to dissolved oxygen, sewage may contain other gases such as carbon dioxide, ammonia and hydrogen sulphide (the products of decomposition) as well as nitrogen dissolved from the atmosphere. These gases, although small in amount, can indicate the degree of sewage decomposition.

Nutrients

Nitrogen and phosphorus are two important nutrients in the operation of a sewage treatment plant and in the receiving watercourse. In the sewage plant they are essential for the growth of organisms involved in the decomposition of organic matter. Sanitary sewage normally contains an excess of both nitrogen and phosphorus. This excess, when discharged into the plant effluent, acts as an undesirable fertilizer, promoting the growth of algae in receiving waters.

Nitrogen is present in wastes in the form of ammonia, nitrite, nitrate, and organic nitrogen, each representing a different stage of waste decomposition. *Total phosphorus* is composed of a number of organic and inorganic compounds which may be present in a soluble or insoluble form. These compounds can be grouped into three categories: namely, orthophosphorus, organic phosphorus and polyphosphorus.

Table 1-2 summarizes the ranges of *typical* nitrogen and phosphorus analyses for a conventional secondary sewage treatment plant.

TABLE No. 1-2

FLOW	NITROGEN				PHOSPHORUS	
	Ammonia mg/l	Organic mg/l	Nitrite mg/l	Nitrate mg/l	Total mg/l	Soluble mg/l
Raw Sewage	15-50	25-85	less than 0.1	less than 0.5	6-12	4-6
Primary Effluent	15-50	25-85	less than 0.1	less than 0.5	4-8	4-6
Secondary Effluent	0-1	5-20	less than 5.0	greater than 10	3-6	2-5

In conventional sewage treatment very little nitrogen and phosphorus are removed, although they may change form chemically. Where high phosphorus removals were noted at activated sludge plants, the raw sewage usually contained aluminum or iron from industrial sources. By adding aluminum, iron or calcium compounds at the treatment plant, total phosphorus can be reduced to less than 1.0 mg/l in the final effluent.

THE EFFECTS OF WASTE DISCHARGES

When certain wastes, including domestic wastewater, do not receive adequate treatment, large amounts of solids may accumulate on the banks of the receiving waters, or they may settle to the bottom to form sludge deposits or float to the surface and form rafts of scum. This accumulation may result in oxygen depletion and also be the source of odours. Primary treatment units in the wastewater treatment plants are designed and operated to remove the sludge and scum before they reach the receiving waters, to prevent as much of this "oxygen-demanding" organic material as possible from entering the receiving water.

Although most streams and other surface waters contain less than 10 mg. of oxygen per litre of water most fish can thrive if there are least 5 mg. per litre and other stream conditions are favourable. However when organic waste is discharged to a stream, bacteria begins to feed on it and decompose or break down the complex substances in the waste into simple chemical compounds. In this process, the bacteria use dissolved oxygen from the water. Where waste flows are high, the population of bacteria may grow large enough to use the entire supply of oxygen from the streams faster than it can be replenished by natural diffusion from the atmosphere. When this happens fish and most other living things in the stream which require dissolved oxygen will die.

Another effect of oxygen depletion, in addition to the killing of fish and other aquatic life, is

the problem of odours. When all the dissolved oxygen has been removed, then *anaerobic bacteria* begins to use the oxygen which is combined chemically with other elements in the form of chemical compounds, such as sulphate, which are also dissolved in water. When anaerobic bacteria removes the oxygen from sulphate compounds, hydrogen sulphide gas is released which has a rotten egg odour. In addition to being odorous, this gas also erodes concrete and can discolour and remove paint from plant structures and nearby buildings. Hydrogen sulphide may form explosive mixtures with air and is also capable of paralyzing the respiratory system.

Some wastes may adversely affect the clarity and colour of receiving waters making them unsitely and unpopular for recreation.

Many industrial wastes are highly acid or alkaline and either condition can interfere with aquatic life, domestic and other uses of water. Before wastes are discharged to a stream they should have a pH similar to that of the receiving water and preferably as near the neutral range as possible (pH7). Industrial waste discharges may contain toxic substances, such as heavy metals or cyanide, which may affect the use of the receiving water for domestic purposes or for aquatic life. Also, odour producing substances may reach levels in the receiving water which are readily detectable in drinking water or in flesh of the fish.

Conventional wastewater treatment plants do not remove a major portion of nitrogen and phosphorus nutrients therefore discharges from such plants contain nutrients capable of encouraging excess algae and plant growth in the receiving waters. These growths hamper domestic, industrial, and recreational uses. Therefore, wastewater treatment facilities located on certain streams or receiving water require installation of phosphorus removing equipment.

Human Health

To this point the physical or chemical effects that the wastewater discharge may have on the uses of water have been discussed. More important, however, may be the effect on human health through the spread of disease-producing bacteria and viruses. Many serious outbreaks of communicable disease have been traced direct to contamination of drinking water, or food supplies by body wastes from a human disease carrier. Although many of the pathogenic organisms are removed by natural die-off during the normal treatment process sufficient numbers could remain to cause a threat to any downstream use involving human contact or consumption. If these uses exist downstream, the treatment plant, without exception, must also include disinfection process of the effluent.

Proper chlorination of a well-treated waste will usually result in a complete kill of these pathogenic organisms. The operator must realize, however, that breakdown or malfunctioning of this equipment could result in the discharge of an effluent which contains pathogenic organisms.

SUBJECT: 1

SEWAGE TREATMENT
OPERATION

TOPIC: 2

BACTERIOLOGY

OBJECTIVES:

The trainee will be able to:

1. Recall and explain the two main objectives of the sewage treatment process.
2. Describe in general terms the reproduction of bacteria as it relates to sewage treatment.
3. Explain the metabolic activities of bacteria and the functions of
 - a) extracellular enzymes
 - b) intracellular enzymes
4. Explain the effect on bacterial growth of:
 - a) temperature
 - b) oxygen
 - c) pH
 - d) food supply
5. Explain the role of bacteria in
 - a) the aeration section
 - b) anaerobic digestion
 - c) aerobic digestion

BACTERIOLOGY OF SEWAGE

OBJECTIVES OF SEWAGE TREATMENT

Sewage is composed of water, organic and inorganic material and living organisms (bacteria).

The main objectives of the sewage treatment system are:

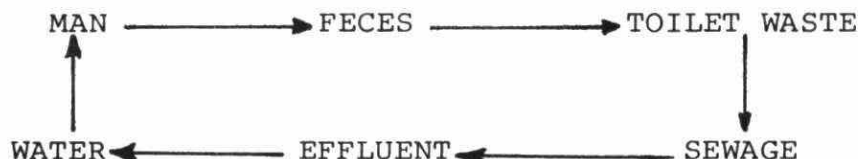
1. To remove organic material (dissolved colloidal or suspended).

The sewage treatment system prevents pollution by transforming dissolved and suspended organic materials (which are composed of carbon, hydrogen and oxygen principally, with small amounts of nitrogen, phosphorus and sulphur) into:

- a) stable mineral compounds
- b) biological cell contents and thence CO_2 and H_2O .
Bacteria are the principal agents active in these processes. If these organic materials were discharged directly to a receiving water, the process of breakdown would still occur, but the O_2 present in the water would all be used; algae would grow on partial breakdown products; and the visible signs of "pollution" would appear - slimes, smells, and dead fish.

2. To eliminate disease-producing agents:

Some human diseases are transmitted from man to man by his own fecal discharges:



In the past, this cycle which results in contaminated water, has played a large part in the spread of disease. However, the present-day method of proper sewage treatment and disinfection of plant effluent, is designed to destroy disease-causing bacteria contained in these wastes, preventing them from entering the waterways. During treatment of sewage its microbial flora changes progressively from that of a predominantly faecal nature to approach that of an enriched fresh-water system. This is because of an enforcement of selective conditions - in activated sludge those organisms capable of growing at the fastest rate are retained.

STRUCTURE OF BACTERIA

The structure of a bacterial cell must be considered in order to understand the function of bacteria within sewage.

Bacterial cells may be characterised by their size, shape and arrangement.

1. Size - Bacteria are extremely small; the majority measure $0.5 - 1\mu$ (micron) in thickness ($1\mu = \frac{1}{1000}$ mm), and $1 - 3\mu$ in length. In terms of inches, it would require 25,000 bacteria to form an inch-long string. An important consequence of the smallness of bacterial cells is that the ratio of surface area to volume is exceedingly high.
2. Shape - Although there are thousands of different species of bacteria, the individual one-celled bacterium have one of two general structural forms. They are: -
 - a) spherical bacterial cells
 - b) rod-shaped bacterial cells.

3. Arrangement - These two structural forms can be observed in the following arrangements: -

- a) individual single cells
- b) pairs of cells
- c) chains of cells
- d) clusters of cells

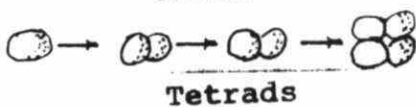
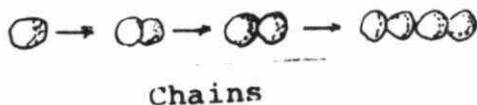
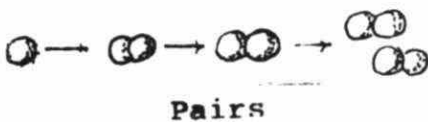
Each bacterial cell has a cell wall which surrounds a substance known as protoplasm. This protoplasm contains all that is required to sustain cell life, including the numerous enzymes which are produced by the cell.

REPRODUCTION OF BACTERIA

Reproduction of bacteria is simply a process whereby one cell divides in half, producing two new cells. This process is called *multiplication by division*; -



Thus, beginning with a single bacterium, the increase in population is by a geometric progression 1 - 2 - 4 - 8 - 16 - 32, etc. The plane in which division takes place determines the arrangement of the resultant cells: -



The time interval required for a cell to divide varies with the type of bacteria and the environmental conditions, and can be anywhere from 30 minutes to several hours. This fast rate of reproduction can be halted by: -

1. an accumulation of the bacteria's toxic waste products (organic acids, etc.)
2. by exhaustion of the food supply
3. by the development of unfavourable environmental conditions.

It has been calculated that if bacterial cells continued to multiply at their maximum growth rate, within a year their combined mass would be equal to that of the sun.

METABOLIC ACTIVITIES AND GROWTH OF BACTERIA

The metabolism of bacteria may be defined as their feeding habits. As a result of these activities:-

1. cell material is formed
2. energy for life is obtained
3. waste materials are eliminated.

These activities are carried out under the influence of *enzymes*. An enzyme is an organic catalyst; it is produced by the living cells, and its function is to produce chemical changes in organic or inorganic substances.

It has been estimated that a single bacterial cell contains several hundred distinct enzymes; these enzymes are capable of performing all the chemical changes associated with life processes. Any impairment of their activity is reflected by some change in the cell, even to the point of death.

Bacterial enzymes are made up of organic and inorganic substances that increase the speed at which a chemical reaction takes place. Each enzyme is specific to one chemical process only; and, therefore, the bacterium must produce a separate enzyme for each chemical process. There are two types of bacterial enzymes:

1. Extracellular enzymes

These are excreted through the cell wall, and function outside the cell. Their main task is to break down the organic compounds into soluble materials so that these can be readily absorbed through the cell wall into the cell.

2. Intracellular enzymes

These are associated with metabolism inside the cell, utilizing the soluble absorbed materials.

Virtually every organic compound occurring naturally or produced biologically can be utilized as food by some kind of bacteria.

Factors Affecting Growth

Bacterial growth is affected enormously by the following physical conditions existing in its environment:

1. Temperature

Since all growth processes are dependent on chemical reactions brought about by enzymes, and since the rate of these reactions is influenced by temperature, it follows that bacterial growth is profoundly influenced by temperature: the optimum for the growth of most bacteria found in sewage is 95-100°F (approximately 37°C).

2. Oxygen - usually dissolved

Bacteria display a wide variety of responses to free dissolved oxygen:

- a) Aerobic bacteria grow only in the presence of free dissolved oxygen.
- b) Anaerobic bacteria grow only in the absence of free dissolved oxygen.
- c) Facultative can grow either in the presence or absence of free dissolved oxygen.

For optimal activity of aerobic bacteria, at least 1 mg/l dissolved oxygen is required.

3. pH

The pH (or acidity/alkalinity) of the environment is another physical condition affecting bacterial growth. For most bacteria, the optimum pH for growth lies between 6.5 and 8.5 (pH 7 = neutrality, pH 2 = acid, pH 9 = alkaline).

4. Food Supply

In the bacterial environment, if too little food is available, growth and reproduction will cease, bacteria will tend to cannibalise each other and will eventually die. If too much food is present, undesirable bacteria may metabolize it faster, creating conditions under which other bacteria cannot survive. Death of all cells, as a result of unfavourable conditions may then occur.

BACTERIA AND THE SEWAGE TREATMENT PROCESS

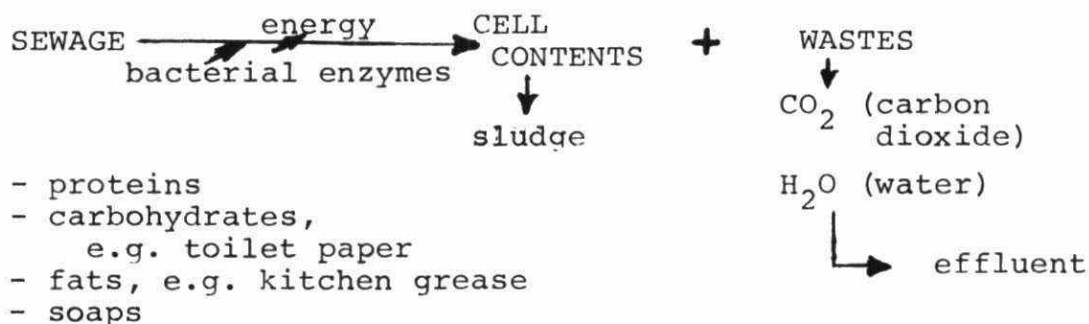
Removal of Organic Material

Raw sewage is generally composed of water, suspended and colloidal solids, and other soluble organic and inorganic substances.

Initial sedimentation of suspended solids takes place in the primary settling tank. The unsettled portion of the sewage enters the activated sludge tanks or the *aeration section* of the plant. Here, the sewage is supplied with tremendous amounts of oxygen for consumption by aerobic bacteria. These bacteria metabolise large amounts of the organic materials, and usually produce a slime or gum which literally holds the bacterial cells together. The groups of bacterial cells clump together and a floc builds up which is then allowed to settle to the bottom of the final settling tank to form sludge. The sludge is either recycled through the aerobic process or drawn off to the aerobic or anaerobic digester. This aeration section is subject to seasonal temperature changes; thus, in winter, bacterial activity slows down, and retention time should be increased to obtain the same effective degree of digestion as is obtained in the summer time. A decrease in temperature also tends to increase the solubility of oxygen.

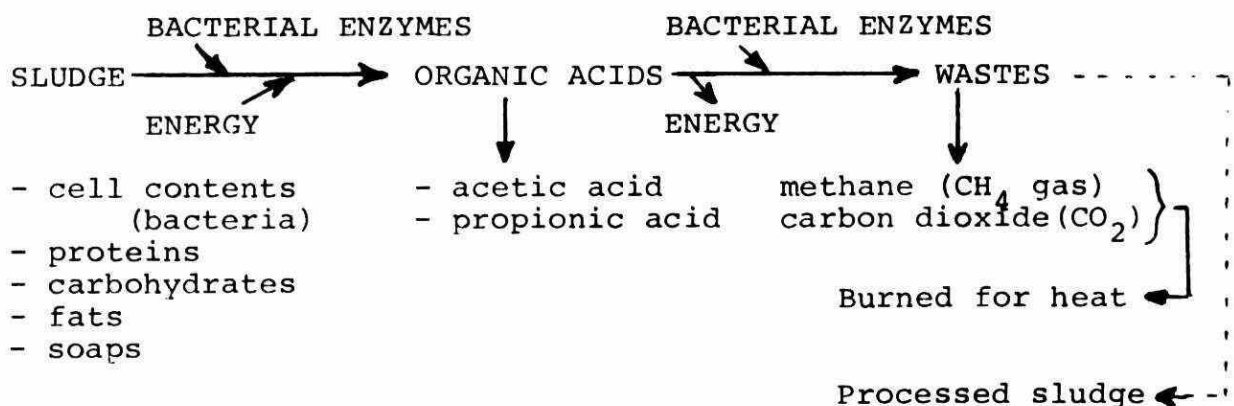
Essentially, the organic material in the sewage has been converted to bacterial cell mass, which settles out as sludge and is retained in the plant. A simplified explanation of the activated sludge or aerobic metabolism process is as follows: -

AEROBIC METABOLISM IN THE ACTIVATED SLUDGE TANKS



The sludge from the aeration section plus the solids from the primary settling tank, enter the *anaerobic digester*. No air is provided and anaerobic bacteria break down the sludge (made up of bacterial cell contents and undigested organic matter) further, and produce organic acids. A second group of anaerobic bacteria utilise the organic acids and produce methane and carbon dioxide. The operation of the digester is particularly sensitive to temperature change and for optimum activity, the temperature should be maintained at 95°F (37°C). Anaerobic digestion operation is also greatly affected by food supply; if sludge is fed too rapidly, the first group of bacteria form the organic acids too rapidly and they accumulate. Conditions become acid and the pH drops to a point where the methane - producing cells will not grow and the process is not completed. As far as inhibitors are concerned, as little as 0.01 mg/litre in sewage (1 mg/litre) in sludge of chlorinated hydrocarbons can inhibit the digestion process. If an upset occurs, they are difficult to restart. The anaerobic metabolism occurs as follows: -

ANAEROBIC METABOLISM IN AN ANAEROBIC DIGESTER



Aerobic Digestion is mainly used for small communities and may be of value for surplus sludge at larger plants. In the initial 3-4 days there is a rapid reduction of suspended solids to a total of 30% in 20 days. Operation at above-ambient temperatures increases the removal rate but is normally uneconomical. Daily or continuous feeding is better than once or twice a week. Air volume requirements are about equal those required for the aeration portion of the plant. Supernatant may be discharged by mixing with treated sewage effluent. In small plants, where the cost of supplied air is not a major proportion of the running cost, operation of a semi-continuous digester is feasible. They are subject to icing problems in the winter because they are normally open. If an upset occurs, they are easily restarted by simply restoring the dissolved oxygen to the tank contents.

The countless numbers of bacteria in the sewage exposing an enormous area of cell surface, and ideal growth conditions causing high metabolic activity are responsible for the rapid changes in the characteristics of the sewage. After passage through a sewage treatment plant, most of the organic and inorganic matter, both solid and in solution, has been removed.

The sludge that remains contains nutrients and organic matter that is only slowly digested; because of its fertilising value it is normally applied to fields. (1/2 square meter/person/year required for disposal).

Elimination of Disease-Producing Agents

In the past, contaminated water has played a large role in the spread of disease. It is a matter of record that when proper water and sewage treatment facilities have been installed in a community, the health of its inhabitants has improved noticeably, and their life span has been extended.

Many bacteria found in sewage are normal inhabitants of the intestinal tract of man and animals. Where an individual is suffering from intestinal disease, disease-causing bacteria will be excreted in large numbers in the feces, and will enter the sewage stream. Some 'intestinal diseases' are Typhoid Fever, Cholera, Poliomyelitis, Hepatitis, and Dysentery.

Some disease organisms will be precipitated out with the large solids in the primary sedimentation tank, and many more with the sludge from the aeration section. Some destruction of these bacteria will occur, as a result of the activity of other microorganisms, and many more will be destroyed during the digestion process. However, the plant effluent will contain the pathogens (disease-producers) that remain suspended, and these must be destroyed before it is released to the receiving stream. For this reason, chlorine, ozone or chlorine dioxide is usually applied to the effluent before discharge. If the treatment is applied efficiently, most of the disease-producing organisms will be destroyed, and any remaining will not be in sufficient number to cause the danger of disease in the receiving water.

Sewage samples for bacteriological analysis are taken as a measure of the efficiency of the disinfection procedure. Total coliforms, fecal coliforms and fecal streptococci are all 'normal inhabitants' of the intestinal tract and are present in large numbers in all sewage. If laboratory tests show that total coliforms have been reduced in numbers by 90-99 percent, it can be assumed that pathogenic forms (which are more readily destroyed by chlorine) have been reduced to a non-hazardous level. Fecal coliforms and fecal streptococci are used as similar 'indicators' of efficiency, as are pseudomonas and clostridia occasionally.

Since pathogenic organisms are present in sewage, a certain amount of care is essential in the performance of required tasks. It is advisable to wear protective clothing when direct contact with sewage is unavoidable; the clothing should be laundered after being discarded. Hands should be washed thoroughly after any procedure involving contact with sewage.

SUMMARY

1. Sewage treatment is biochemical in character and bacteria are the principal agents in the decomposition of organic and inorganic materials.
2. The bacteria are not acting in any special way in sewage treatment. It is a natural process which has been harnessed for the benefit of man.
3. The mechanism which enables rapid decomposition of wastes at normal temperatures is the enzyme system. Without bacterial activity, the sewage treatment process would require large amounts of energy, e.g. burning in a furnace. This would be very costly.
4. All treatment processes are made optimal for the required bacterial activity.

SUBJECT: 1

SEWAGE TREATMENT
OPERATION

TOPIC: 3

PRIMARY TREATMENT

OBJECTIVES:

The trainee will be able to:

1. Recall the purposes of flow records.
2. Name five flow control devices used in pumping stations.
3. Explain the purposes for installing preliminary treatment devices in sewage treatment.
4. Name, describe and explain the functions of the preliminary treatment devices in sewage treatment plants.
5. Name three types of grit removal devices and explain their operation.
6. Give three reasons for pre-aeration of raw sewage.
7. Describe the function of the primary clarifier.
8. Describe the operation of a lagoon, using a diagram.
9. List four common problems encountered in lagoon operation.

PRIMARY TREATMENT OF SEWAGE

PUMPING STATIONS

Sewage coming from the sewers enters the treatment facility by *gravity flow*, by *pumping stations*, or *ejector stations* located on the sewage collection system or at the plant site. See Figure 3-1

Sewage is usually screened at pumping stations to protect the mechanical equipment in the station.

Flow entering a pumping station is recorded. It enables the operator to assess the flow entering the plant, to verify plant flow recording devices, or to detect infiltration in the collector system. Pumping stations located at critical points on the sewage collection system may be equipped with standby emergency pumping equipment to ensure that service is maintained at all times, even during major power interruptions.

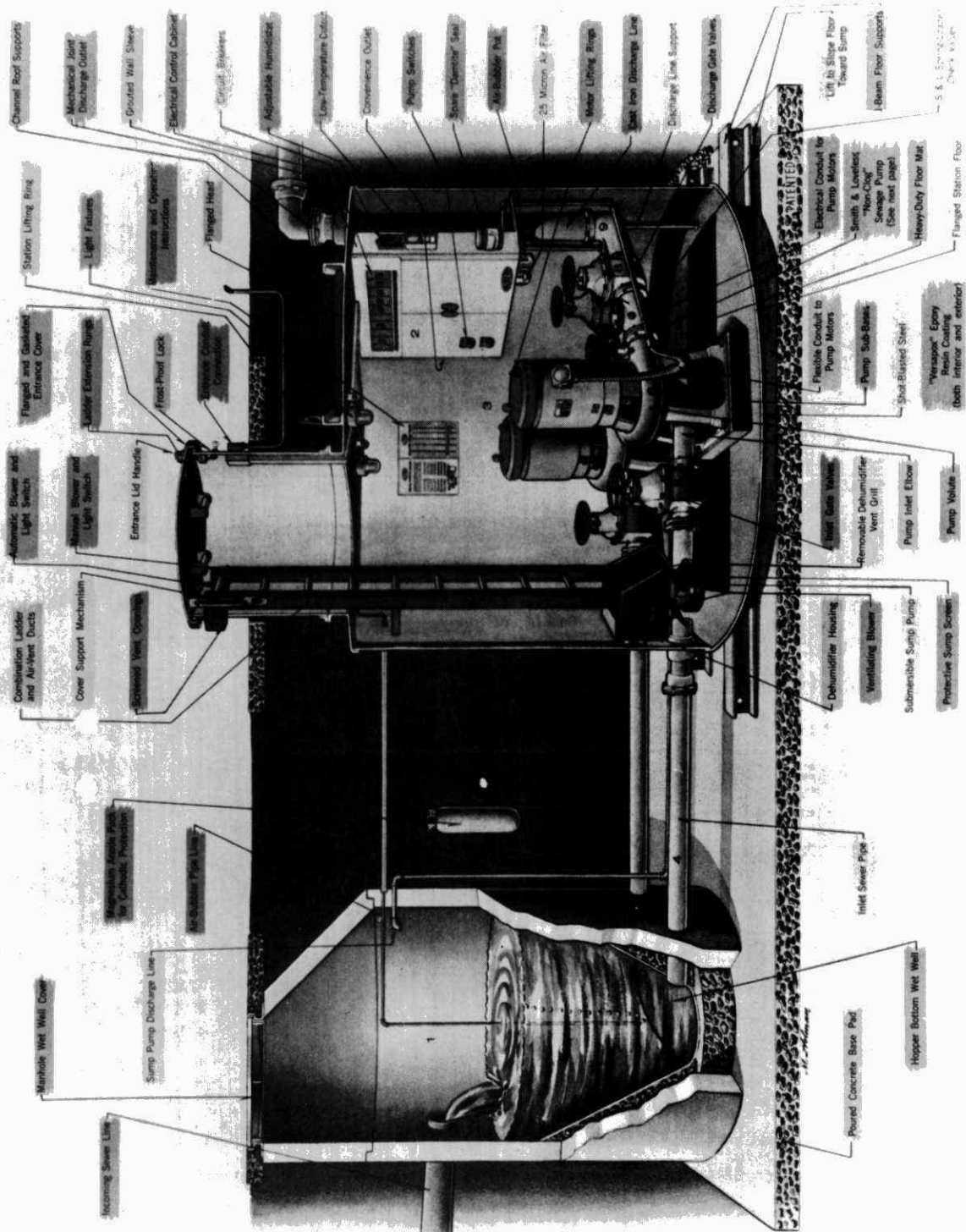
FLOW CONTROL

Flow through a pumping station is controlled by one of the following devices:

1. Manual Operation
2. Float System
3. Bubbler System (Pneumatic)
4. Electric System
5. Flowmatcher

Manual Operation

It is usually not economical to have an attendant at the station at all times; however, all stations should have manual control. It allows the attendant some flexibility when visiting the station. By having manual control, the attendant can test the operation of the equipment, and, in case of emergencies, can actually control the operation.



Sewage Pumping Station

Figure 3-1

(Courtesy of Smith & Loveless)

Float System

Simple, moderate in cost but somewhat troublesome in most raw sewage applications. The rise and fall of the float actuates mercury-tip switches that start, stop or change the speed of the pumping units.

Bubbler System (Pneumatic)

A small air supply causes bubbles to escape from an open-ended pipe submerged in the wet well below the lowest level to be controlled. The pressure of the air in the pipe manifold changes with the submergent depth and actuates pressure sensitive switches that start, stop or control the speed of the pumping units.

This system offers distinct advantages over the float system for use in raw sewage because the air pressure in the pipe prevents clogging, and there are no moving parts in contact with the sewage. The system is relatively inexpensive, reliable and easily serviced.

Flow Control System - Electric

This system, usually of the probe type, consists of a pair of insulated electrodes positioned to contact the liquid surface at pre-determined levels. When contact is made the electric circuit is completed, and a signal is relayed to the pumps. If the liquid level is rising, the signal will activate the pumps until the level has dropped to the desired height. At this point, the electric circuit is broken, and the pumps stop until the liquid level once again rises to complete the electric circuit.

An electric system is relatively expensive and generally has a tendency to foul in raw sewage applications and requires a more frequent maintenance schedule than other systems previously described.

Flowmatchers

To fully understand the Flowmatcher system, a knowledge of the wound rotor induction motor is required. Basically, the Flowmatcher controls the operation of the wound rotor induction motor.

A Flowmatcher increases or decreases the resistance applied to the rotor of such a motor by altering the level of the electrolyte surrounding the resistance plates within the Flowmatcher unit.

The unit can be used in a continuous pumping operation or a start-stop operation.

The start-stop operation is preferred, since at low speeds (50% of normal full speed) wound rotor motors running for long periods exhibit a very poor power factor, will heat up and could cause *spark grooving* on the surface of the slip rings and brushes.

The units are normally used in critical operations and are subject to vigorous preventative and breakdown maintenance programs.

It is recommended that systems using Flowmatchers maintain spare components at all times. A list of suggested parts is available from the Ministry of the Environment, Utility Operations Regional Managers.

PNEUMATIC EJECTORS

Sewage is directed to a tank causing the air in the tank to escape and be replaced by the sewage. The air exhaust is then closed and a compressed air inlet is opened which forces the sewage out the discharge pipe. The inlet pipe and the discharge pipe are each equipped with check valves to prevent back flow when filling and emptying.

Compressors are selected, based on the total head and rate of discharge required.

Advantages of this type of system are:

1. Relatively few moving parts in contact with sewage.
2. It is relatively clog free.
3. Sewage is completely enclosed.
4. The operation of this unit usually requires relatively simple maintenance procedures.

PRELIMINARY TREATMENT

Preliminary treatment devices are designed to remove or reduce in size large solids, grease, scum and grit before any further treatment of sewage. The removal of these materials protects pumps and other treatment devices from possible damage. If the preliminary treatment devices do not function as intended, maintenance costs for pump repairs, digester and clarifier clean-outs, etc., will be increased. The following units are usually associated with preliminary treatment:

1. Screens (coarse, bar, fine)
2. Comminutors (comminutors, barminutors, rotogrators)
3. Grit Removal Units (channel, aerated tanks, centrifugal separators)
4. Pre-aeration

SCREENS

Screens are used to remove materials which may damage equipment, interfere with the process or which are aesthetically undesirable in the effluent. Two basic types available are coarse screens and fine screens.

Coarse Screens

Coarse screens (commonly called *trash rack* or *bar screens* Figure 3-2) generally have bars spaced from 3/4 to 6 inches. The screens are usually installed at an angle to facilitate manual cleaning, but some units are available that can be mechanically cleaned. Trash racks are normally installed at the pumping stations.

Fine Screens

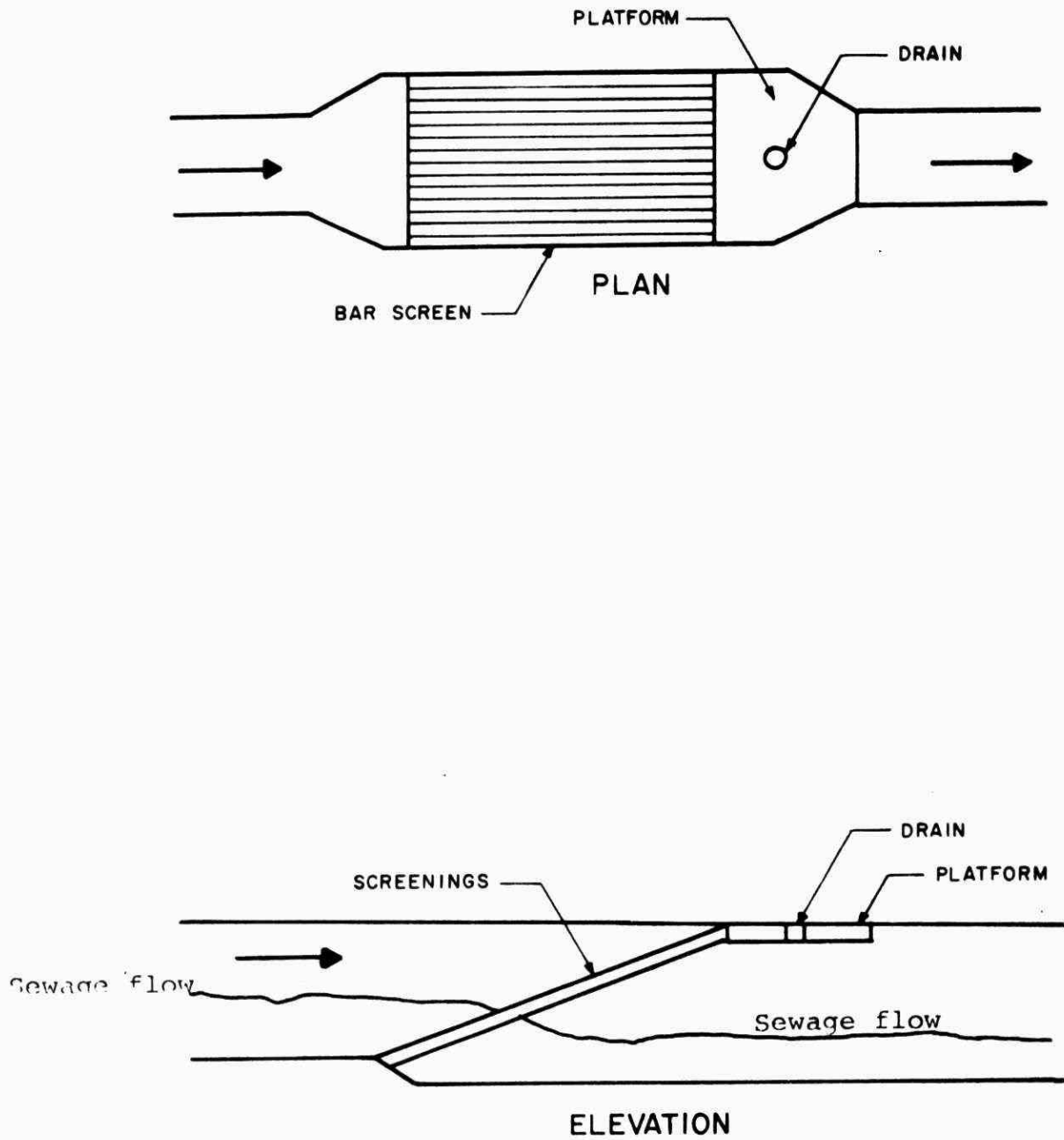
Fine screens were originally used in place of sedimentation tanks. Presently they are not commonly used in sewage treatment because the mesh will accumulate material and plug very quickly, causing what is called a *headloss* in the system. There are other operating and economical problems as well.

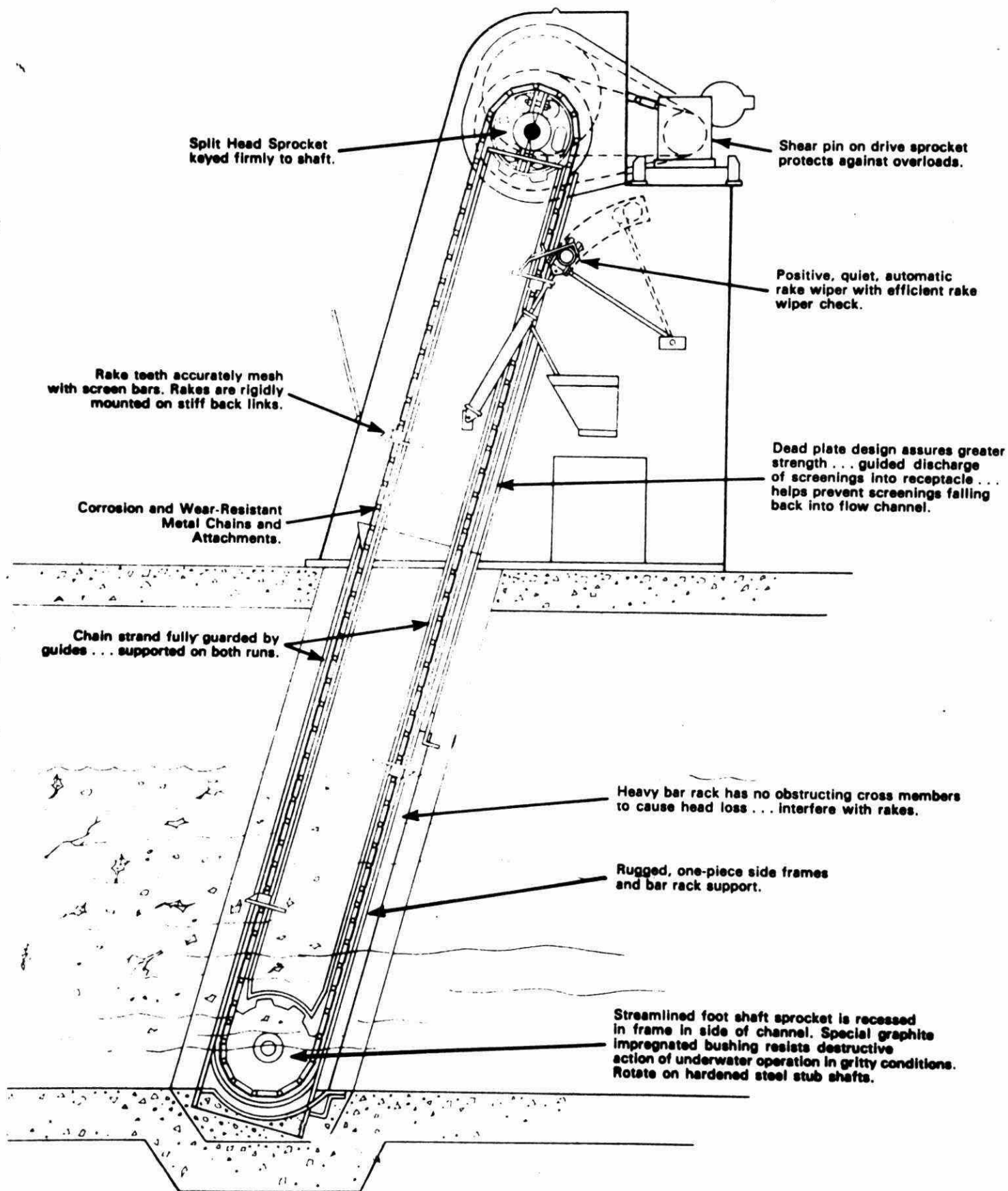
PRIMARY TREATMENT

BAR SCREEN

HAND RAKED

Figure 3-2





Profile View of a Mechanical Bar Screen

Figure 3-3

(courtesy of REX)

Mechanically Cleaned Screens

Vertical or inclined bar screens are cleaned by a mechanical *rake*. The accumulated material on the screen is pulled up the screen and "wiped" off into a hopper. Screenings are regularly removed from the hopper to prevent nuisance odours and ensure adequate capacity for incoming screenings. See Figure 3-3.

Cleaning Screens

During dry weather periods, *coarse trash racks* should be cleaned daily; during storm periods, they should be cleaned two to five times per day to maintain a free flow of sewage through the process.

Failure to clean the screens can result in one or more of the following:

1. Septic action upstream of the sewer.
2. Surcharge of the sewers.
3. Shock load on sewage units when the screens are finally cleaned.

Coarse screens, when mechanically cleaned, offer the following advantages:

1. Reduced labour costs.
2. Better flow conditions in the process.
3. Produce less nuisance.

The volume of material or *screenings* removed is difficult to estimate accurately. Generally, screens with openings of $1\frac{1}{4}$ to $2\frac{1}{2}$ inches will collect between 1 and 12 cubic feet of screenings per million gallons of sewage. Figure 3-4 shows the maximum and average quantities of screenings that can be removed.

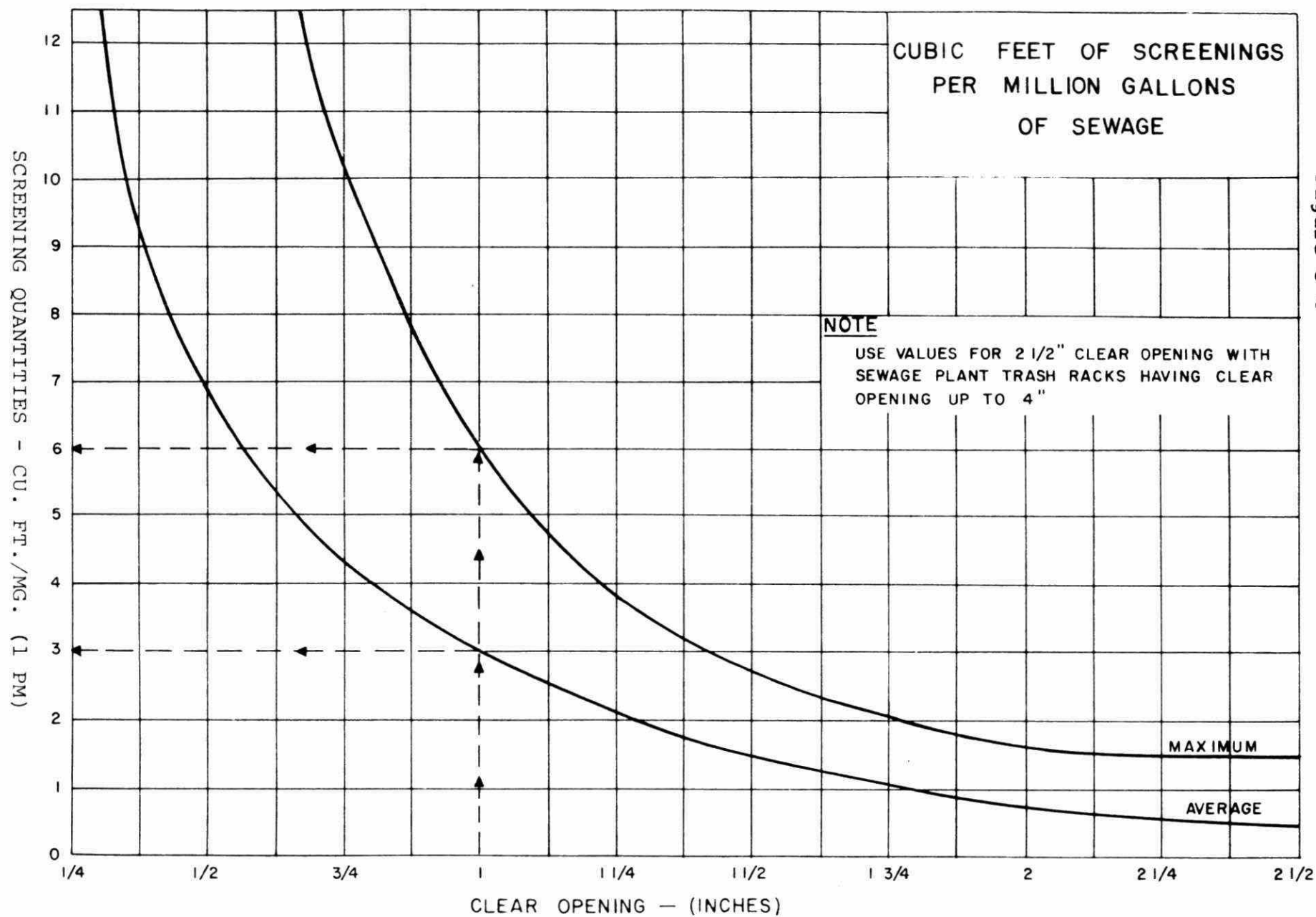


Figure 3-4

Disposal of Screenings

The screenings may be disposed of by burial, incineration, grinding or digestion. Burying and incinerating are the usual methods of disposal because they are the most economical methods. Most municipalities use one of these methods for disposal. *Contact your local Public Health Unit and observe local by-laws before burying or incinerating screenings.* Remove screenings in covered containers. When burying screening odour may be prevented by sprinkling powdered lime or other odour control chemicals on the material. An earth cover of one to two feet will usually give the best results for bacterial activity. Grinding devices have been used in the past; the ground screenings are redirected to the influent flow for treatment in the process. This method has proved unsatisfactory however, as it may create digester problems. Screenings received from grinders have caused digester foaming and excessive scum blankets.

COMMINUTION OF SEWAGE (Figures 3-5 and 3-6)

Comminutors, Barminutors, or Rotogrators are trade names used by different manufacturers to identify their Shredding devices. This piece of equipment is used to shred and grind large material small enough to pass through the screens of the grinding unit. Shredders should be installed with a by-pass equipped with a bar screen to facilitate removal of settled material and allow inspection of the equipment components such as the cutting edges.

Comminuting devices are normally operated continuously and are usually located ahead of the grit removal units.

GRIT REMOVAL UNITS

Grit such as sand, stones and gravel may find its way into a sewer system and be carried by the sewage to the treatment plant.

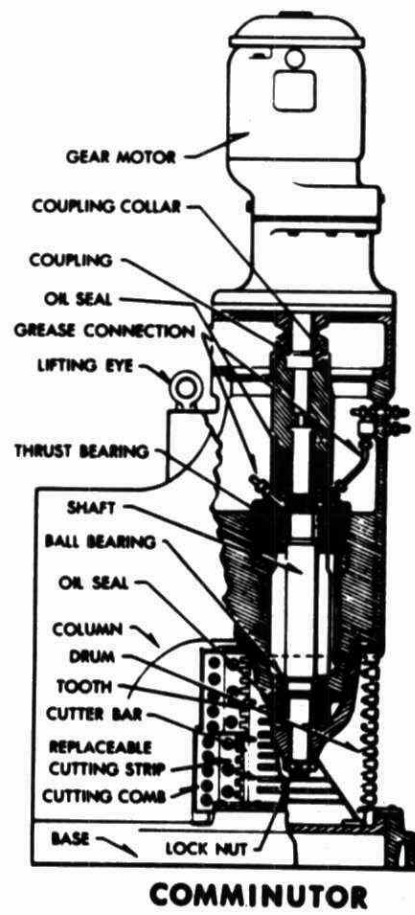
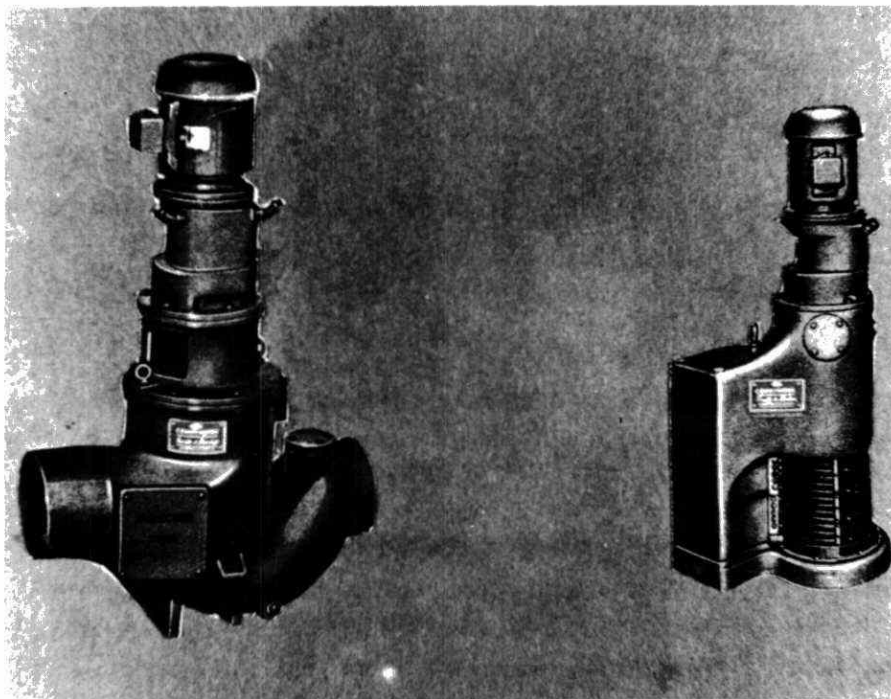


Figure 3-5



Inline Comminutor

Open Channel Comminutor

Figure 3-6

(Courtesy of Smith & Loveless)

Grit removal units are installed after screening equipment in the process to protect mechanical equipment from abrasion, avoid pipe clogging, and reduce the sedimentation load on the primary clarifier. Grit removal devices include:

1. grit channels
2. aerated grit chambers
3. mechanical units

Grit Channels (Figure 3-7)

Grit particles will settle faster than organic putrescible solids because they are heavier. Grit channels are usually designed to maintain a velocity of 1 foot per second at design flow which is usually sufficient to keep the organic matter in suspension while allowing the heavier particles to settle. Grit channels are usually rectangular and velocity control is achieved by installing a weir at the effluent end of the channel. Another velocity control device, though seldom used, is a Parshall flume.

Aerated Grit Chamber (Figure 3-8)

Grit chambers using air to separate the lighter materials from the heavier ones are called *aerated grit chambers*. Sewage flows into the aerated grit chamber and the heavier particles settle to the bottom as the sewage rolls in spiral motion from entrance to exit. The lighter organic particles eventually "roll" out of the tank. The grit at the bottom of the tank is directed to a grit hopper where it is removed by a clam shell bucket or air lift units.

Detritus Tank (Figure 3-9)

Short-period sedimentation in a tank that operates at substantially constant levels produces a mixture of grit and organic solids called *detritus*. The lighter organic solids are subsequently removed from or washed out of the mixture.

Several manufacturers specializing in sewage disposal equipment have perfected this type of equipment. For example, one such unit not only removes the grit but also washes it.

Figure 3-7

GRIT CHAMBER

HAND CLEANED, GRAVITY TYPE

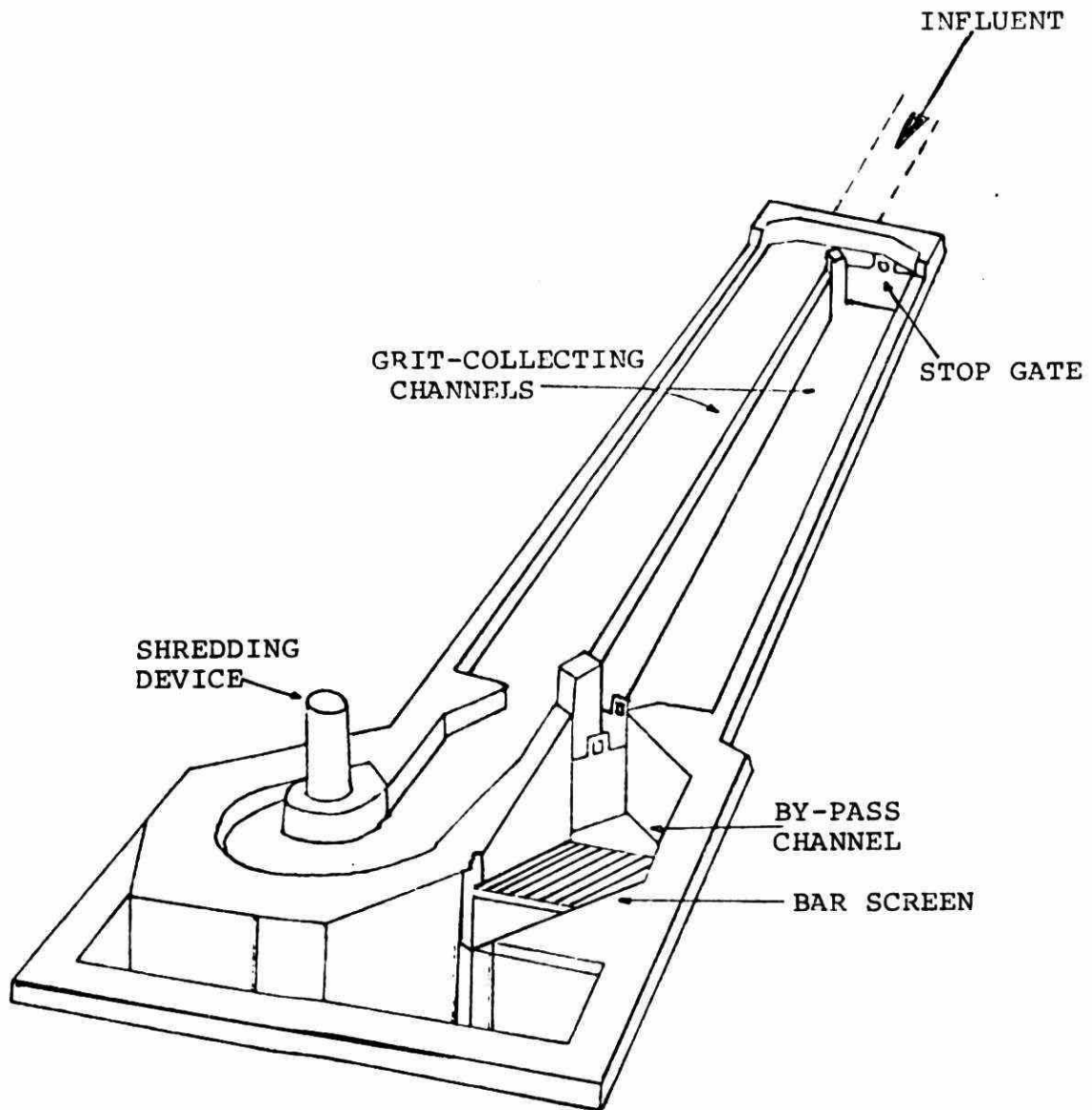
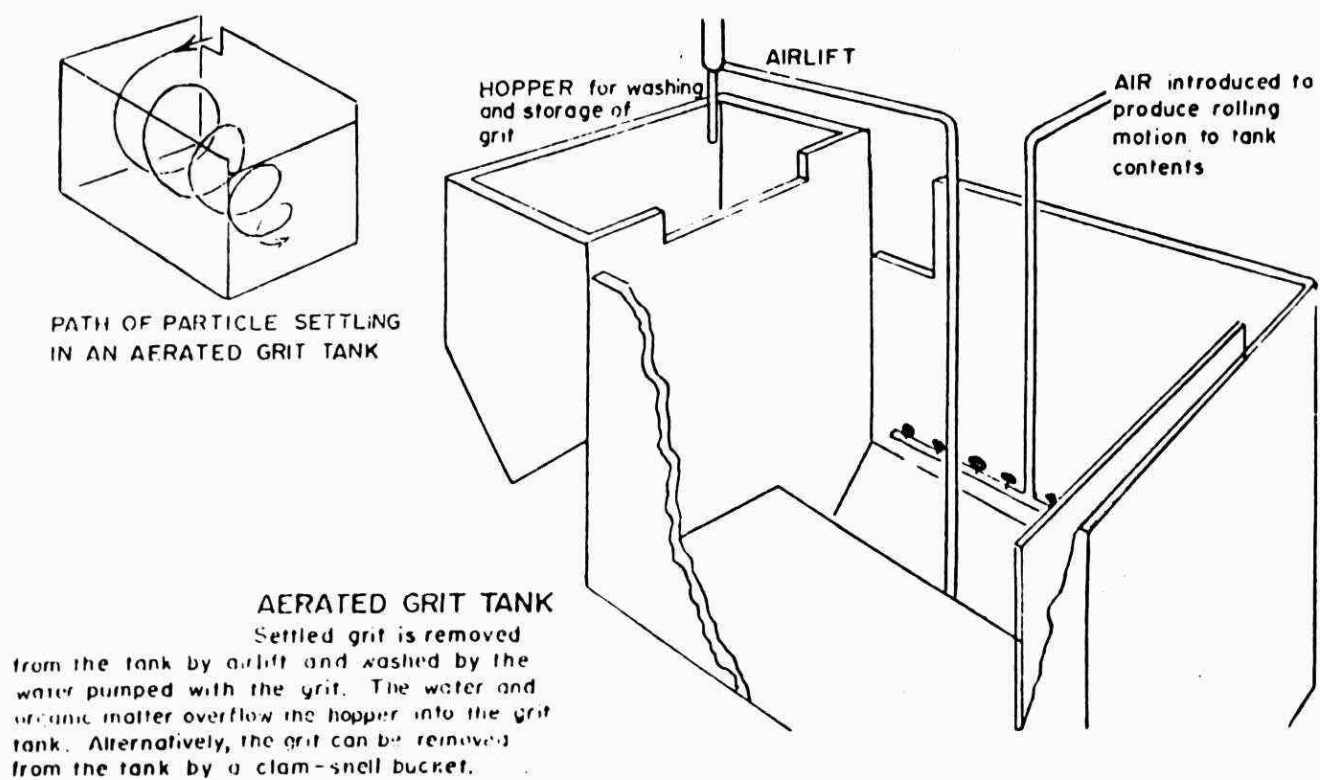


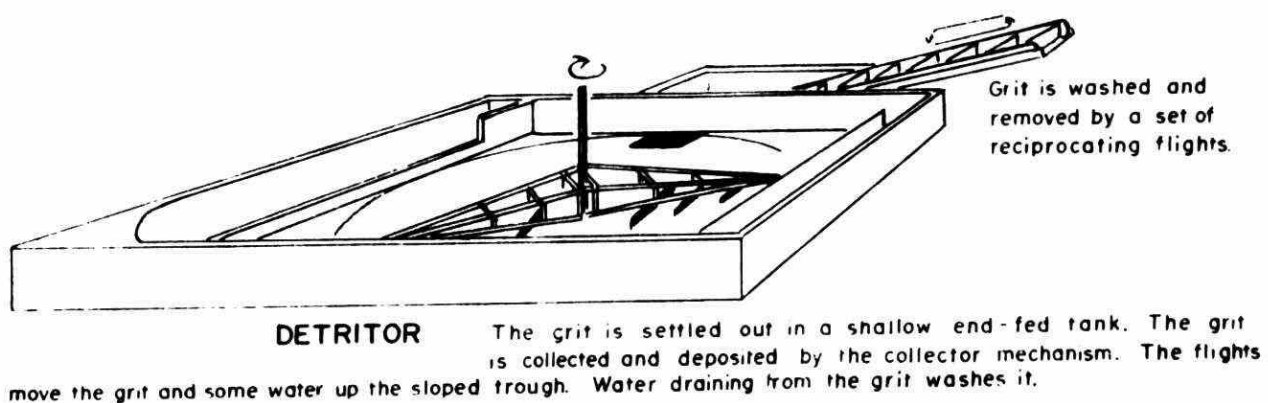
Figure 3-8



The grit-collecting mechanism is installed in a square, shallow, concrete tank with filled-in sloping corners. Sewage enters along one side of the tank through adjustable vertical gates, which are set to provide a uniform influent velocity across the entire width of the unit. Then the sewage flows in straight lines across the tank and overflows at a weir constructed along the outlet side of the tank.

The collecting mechanism consists of two structural-steel arms, attached to a vertical shaft and fitted with outward raking blades with scoops on the ends. As the rakes revolve, settled grit is plowed outward to the radius where the end scoops collect and discharge it to a hopper at one side of the tank.

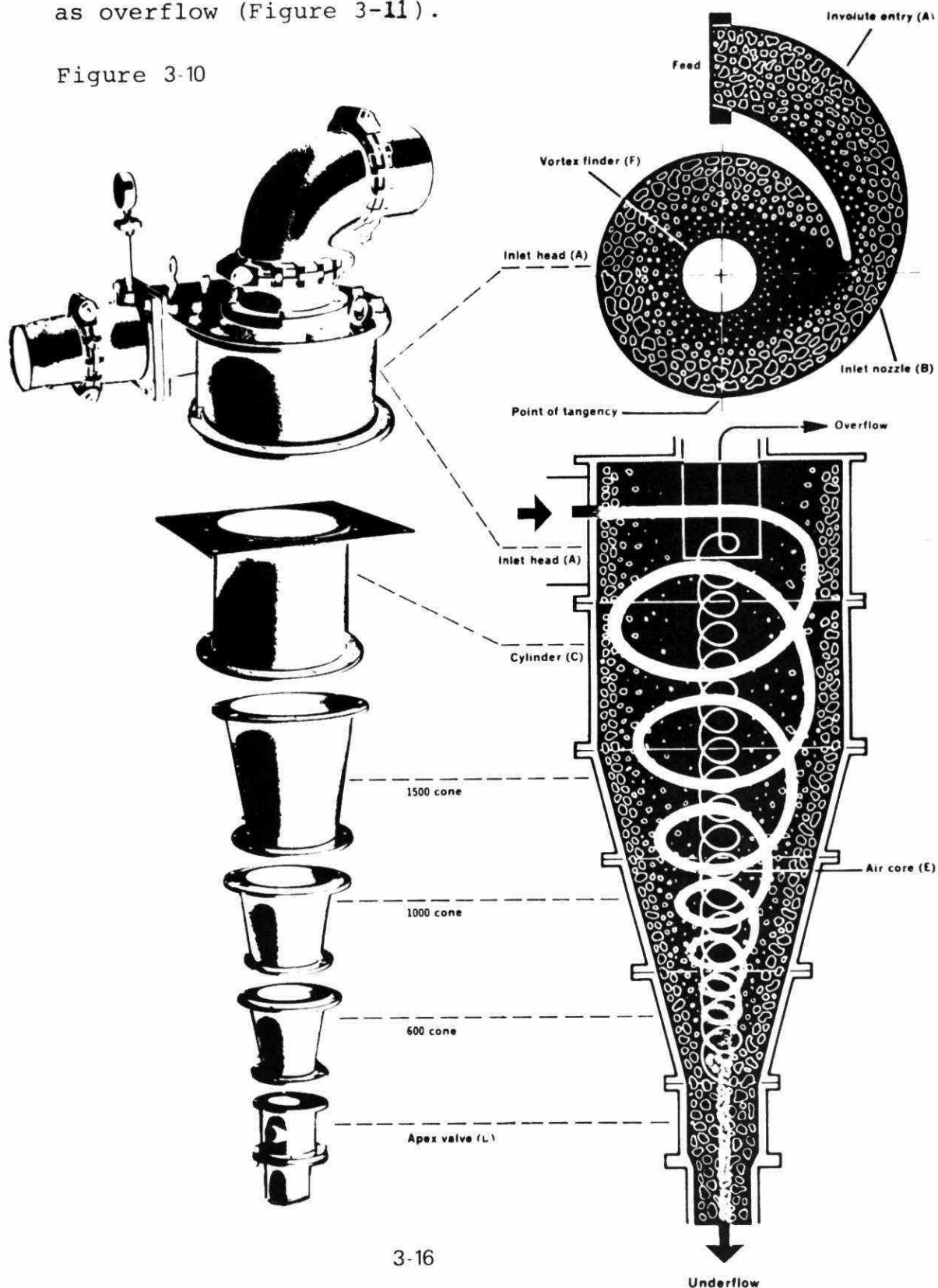
Figure 3-9



(d) Centrifugal Separators

Grit removal is possible by mechanical means such as a centrifugal unit. Centrifugal units are usually liquid cyclones: the waste water is introduced tangentially into a cylindrical conical housing. The heavier larger particles of grit are thrown to the outside wall and collected for disposal. The waste water leaves the centre of the housing as overflow (Figure 3-11).

Figure 3-10



Grit Disposal

Average figures indicate that from 3 to 8 cubic feet of grit can be collected per million gallons of sewage. The dirt must be removed before it is carried by the stream flow into the primary clarifier, digester, or chlorine contact chamber. It is a good practice to make periodic checks to ensure that the grit is not being carried to the clarifier, or digester, or chlorine contact chamber, where it would still have to be removed but with much more difficulty and expense.

The grit removal facility can reduce unnecessary maintenance costs more than any other unit. If these facilities are malfunctioning because of problems or improper operation, the result will be plugged lines, abraded impellers, and grit filled treatment tanks.

The disposal of grit is usually done by burial, or dumping at the municipal dump or on a landfill site. If the disposal is carried out at the plant, unwashed grit from the removal facilities should be stored in covered containers and removed to the disposal site daily. If the grit is adequately washed (having less than 3% volatile solids remaining as determined by lab tests) it may be used as fill around the plant or may be used to re-sand sludge drying beds.

PRE-AERATION

Aeration basins may precede or follow screens and grit chambers. In general, pre-aeration tanks are designed for detentions of 5 to 15 minutes for grease removal, using 0.01 to 0.1 cubic foot of air per gallon of sewage treated. If flocculation of the fine suspended solids in the raw sewage is also attempted, the detention period must usually be extended to at least 15 to 60 minutes, the average time being about 30 minutes.

Raw sewage is aerated for one or more of the following purposes:

1. *To remove gases from the sewage, especially hydrogen sulphide, which create odour problems and increase the chlorine demand of sewage. The release of gases and the addition of oxygen reduce odours in septic sewage. For effective results an aeration period of 30 minutes to several hours may be required.*
2. *To promote flotation of excessive grease, which then can be removed from the raw sewage at an early stage in its treatment. Aeration increases the amount of skimmings or grease because the rising air bubbles attach themselves to heavier-than-water particles causing buoyancy. This buoyancy holds the grease particles in the surface flow. Some de-emulsifying of the grease also occurs which separates it from the sewage. The skimmings are removed several times a day by hand or by skimming devices, or they may be discharged to the primary settling tanks for removal.*
3. *To aid in the coagulation of the colloids (finely divided suspended solids) in the raw sewage for the purpose of obtaining a higher removal of suspended solids by primary settling.*

PRIMARY TREATMENT

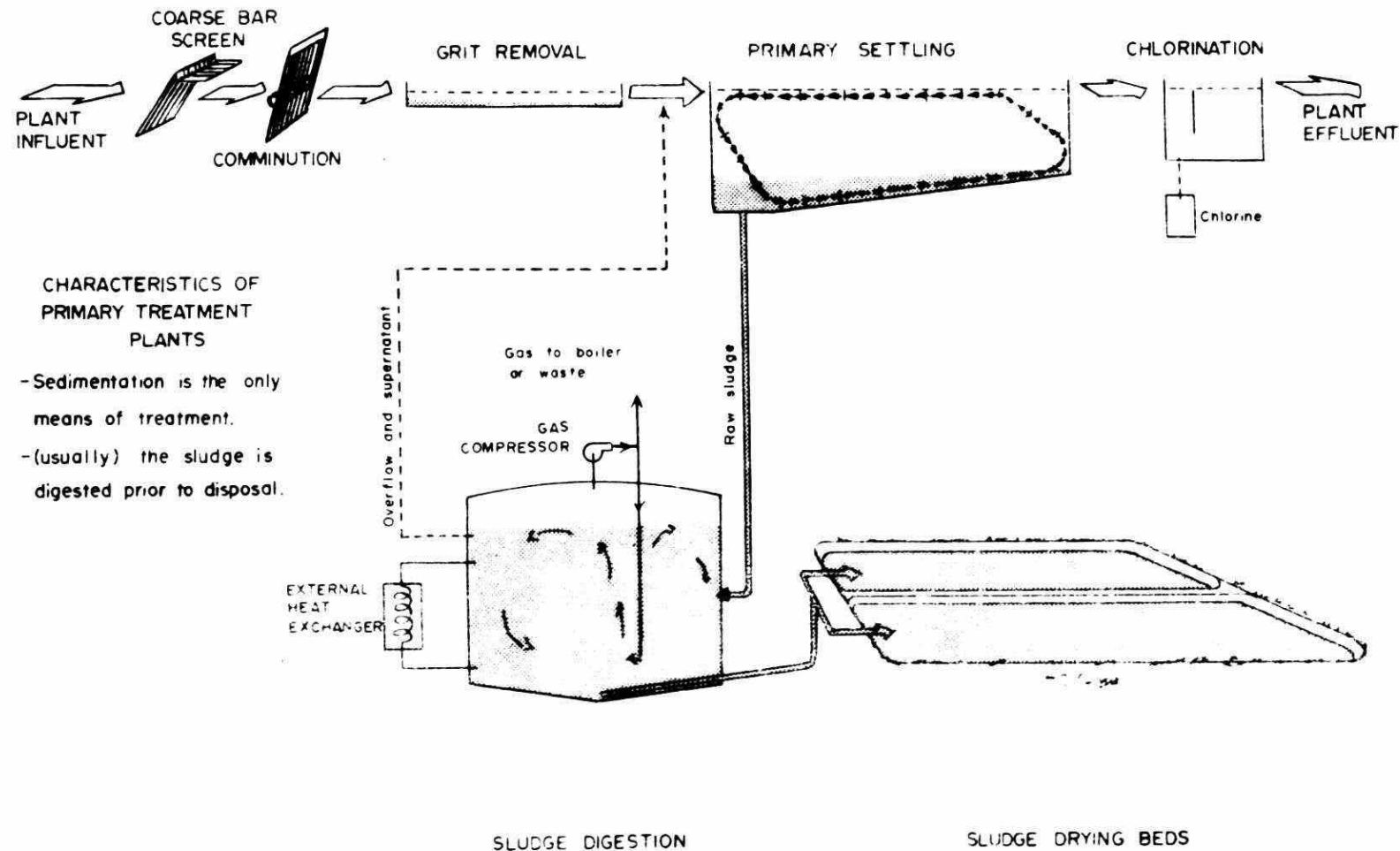
Primary treatment devices remove the settleable solids and reduce the suspended solids content of the sewage by 40 to 60%. In so doing, the BOD of the sewage is also reduced by 30 to 40%.

The following units may be considered when discussing the primary treatment process (See Figure 3-11):

FIGURE No. 3-11

PRIMARY TREATMENT PLANT

Shown here with a grit channel, rectangular sedimentation tank, single stage anaerobic digester employing gas mixing, and a sludge drying bed.



CHARACTERISTICS OF PRIMARY TREATMENT PLANTS

- Sedimentation is the only means of treatment.
- (usually) the sludge is digested prior to disposal.

Principal Units

1. Sedimentation Tanks (clarifiers Figures 3-12 and 3-13)
2. Waste stabilization ponds

Secondary and Associated Units

1. Digesters
2. Vacuum filters
3. Chlorine contact chambers
4. Sludge drying beds

The primary clarifier removes, to varying degrees, the remaining settleable solids in the raw sludge. *It is the most important single facility in primary treatment.* Clarifiers are sized on a basis of settling rates and required detention time. The principle of operation is to slow down the sewage as it moves through the tank, allowing the settleable and suspended solids enough time to settle out. In so doing, the Biochemical Oxygen Demand (BOD) is also reduced by approximately 30 to 40%. Floating solids and scum are also removed in these tanks. Sludge solids are directed to digesters or vacuum filters for further treatment. Effluent water is chlorinated before it is released to the receiving stream.

Figure 3-12

MECHANICAL SLUDGE COLLECTION
RECTANGULAR TANK

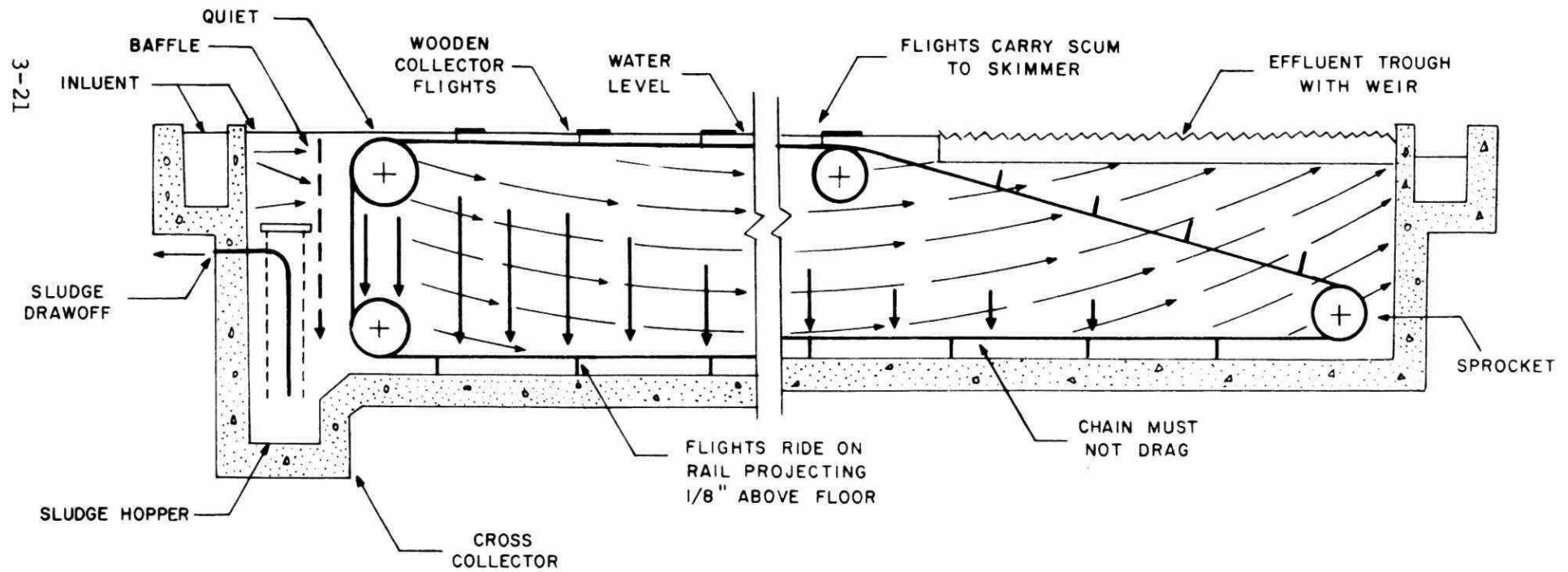
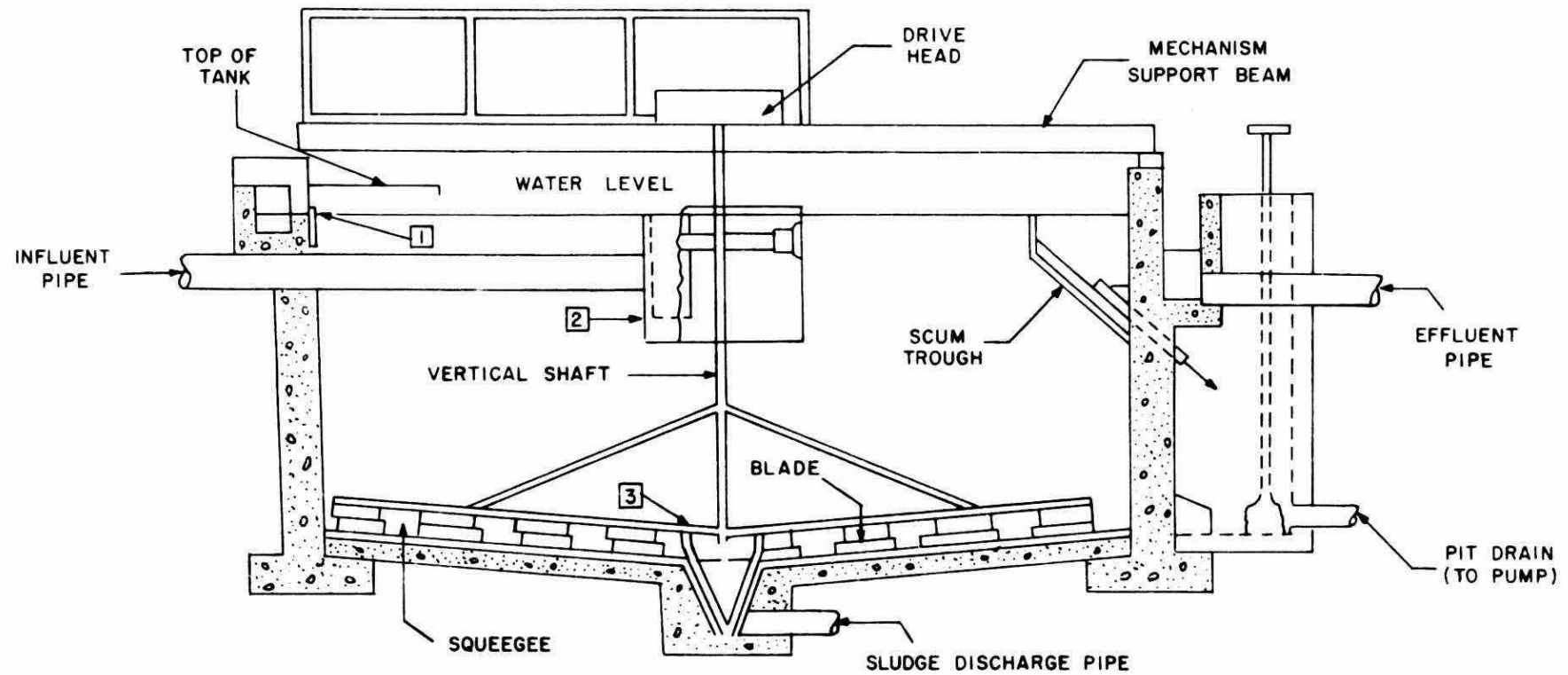


Figure 3-13

CIRCULAR SETTLING TANK
ONE TYPE



1 SAW TOOTH WEIR

2 EFFLUENT WELL

3 RAKE ARM

Operation of Sedimentation Tanks

Clarifiers or sedimentation tanks assume a variety of shapes: rectangular, square, round, and even octagonal.

In *rectangular* tanks, the sewage enters at one end and the effluent overflows the weirs near the opposite end.

Collectors operating in rectangular tanks consist of two endless chains operating on sprocket wheels and supporting wood crossbars, or "flights". The flights push the sludge to a hopper at the end as they move slowly along the bottom. For primary sedimentation the flights should move back at the surface to push the scum toward a trough at the opposite end. The trough extends across the tank and terminates in a pipe which passes through the tank wall. A valve in the pipe is opened before scum is withdrawn. The scum accumulations are pushed into the trough manually and run through the pipe to a sump for further handling. Some tanks have cross-flight skimmers to do this skimming mechanically instead of manually.

The *square* tanks can have the inlet on one side with the outlet opposite, or can be centre-fed with effluent weirs along the entire periphery. The sludge collector mechanism rotates about the centre of the tank, scraping the settled sludge into the pit in the centre and an arm on the surface moves the grease and scum to a hopper located on one side of the tank.

Circular tanks can be either centre-fed or peripherally-fed. The sludge collector mechanism is similar to that of the square tank.

In general, sludge collecting mechanisms in circular tanks are operated over longer periods than collectors in rectangular tanks. Collectors should be run often enough to prevent a build-up of solids in the tank from causing an

undue load on the mechanism at start-up and damaging the equipment. Also, the tank volume is reduced, resulting in a lower retention period. Solids may decompose, producing gas in the settling tank and floating sludge. Before sludge is removed from the tank the mechanism should be run long enough to assure satisfactory collection of solids in the bottom of the sludge hopper.

Establish and maintain proper time schedules for operation of the mechanical cleaning equipment and for the removal of sludge from the tank. Schedules must be determined for individual plants. General maintenance should include daily cleaning of all vertical and inclined walls and the removal of all material from baffles and algal growths from weirs.

Scum Removal

Scum is formed by foreign matter that rises to the surface. It should be pumped out of the tank before pumping the sludge, if possible. By doing this, any grease remaining in the pipes will be scoured by the sludge when it is removed. Removal of scum, floating garbage and grease is essential for efficient operation of settling tanks. A scum barrier or baffle is generally provided in the flow path between the centre of the tank and effluent weir. Excessive skimming will result in too much water being carried out with the scum, while insufficient skimming will permit scum to flow around or under the baffle and escape with the tank effluent. Scum must be removed daily, and ideally, small amounts should be removed continually rather than a large batch at one time.

Chemical Precipitation

Chemical precipitation is a modified sedimentation process in which a coagulant is employed to improve the efficiency of settling. Chemicals used include alum, ferric chloride and lime. Proper mixing of these is essential and the dosage will vary according to the characteristics of

the sewage being treated. Efficiencies of 80% to 90% removal of suspended solids and 50% to 55% removal of BOD are common when using chemical precipitation. However, the use of chemicals is an expensive operation and produces a high volume of sludge which may be difficult to dispose of, further adding to operating costs.

WASTE STABILIZATION PONDS (LAGOONS)

A waste stabilization pond is a shallow excavation designed and constructed to receive raw or pretreated domestic sewage and some organic industrial wastes in which stabilization is accomplished by several natural self-purification "phenomena". (See Figures 3-14 and 3-15).

The purification process in the lagoon is dependent upon the combined action of wind, sunlight, temperature, sedimentation, bacteria and algae. A portion of the solids in the raw sewage settles immediately after the sewage enters the pond while the remainder are dispersed by wind action in the overlying water.

The bacteria, which is naturally present in the sewage and the soil, feed on the organic matter and by digestion convert it into substances which may be discharged into the receiving stream without creating objection or a depletion of oxygen. The abundant supply of soluble nutrients which include carbon dioxide, ammonia, nitrogen and other chemical substances released by the bacteria provide an ideal source of food supply for the algae which grow prolifically near the surface of the pond. The algae is dependent upon sunlight for their activity and release large quantities of oxygen except during periods when the sunlight is excluded. The oxygen in turn is utilized by the bacteria and is in fact absolutely essential to their activity.

Ice cover is a barrier to both light and wind. When snow is present, light penetration is further impaired. Consequently, stabilization ponds become anaerobic soon after ice formation. Accompanying low temperatures also

slows down the bacterial action. At the same time, salts and other sewage constituents become more concentrated under the ice of non-overflowing installations, not only from the continual application of raw sewage, but also by exclusion from ice in the process of freezing. Therefore, melting ice can be expected to provide good quality dilution water in the spring.

Experience of the several states and provinces where lagoons have been used extensively indicate that the degree of treatment provided by waste stabilization ponds is generally equivalent to that provided by conventional activated sludge plants. The reduction in pollution as measured by BOD and suspended solids is commonly in the range of 85 to 95 per cent. Reductions in coliform organisms of more than 99 percent have been reported. No practical method is known today for the disinfection of the lagoon effluent to be discharged into the receiving stream. The high concentration of algae makes disinfection somewhat impractical. It is, therefore, essential that the pond be operated so that no overflow occurs when chlorination of a plant effluent would normally be required to protect the use of the natural waters.

In line with the province's guidelines for phosphorus removal for sewage treatment plants located within the compliance area the following program is in effect:

1. Seasonal retention lagoons - this includes those with 180 or 365 day retention - batch treatment with alum or ferric chloride is conducted, achieving even distribution through the use of an outboard motor boat. The phosphorous and algae as well precipitates to the bottom of the cell and the top portion is decanted.
2. Continuous discharge lagoons. In this case a permanent structure is located at a convenient location prior to the lagoon influent so that the chemical may be added to the raw sewage to achieve adequate mixing.

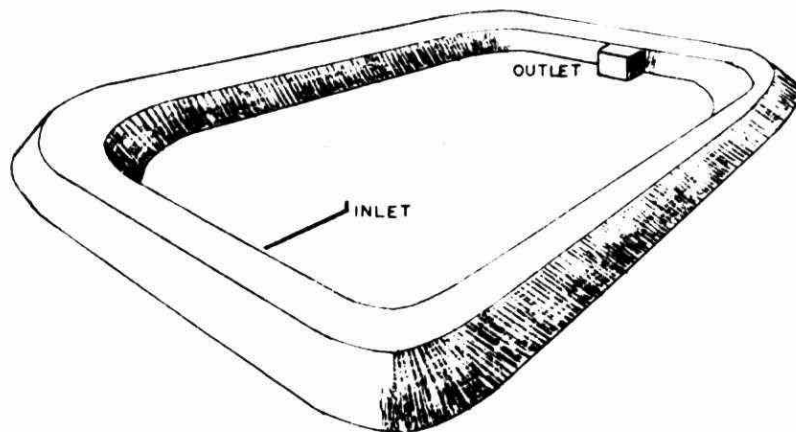


FIGURE 3-14 WASTE STABILIZATION POND The pond has a flat floor and the normal water depth is about five feet.

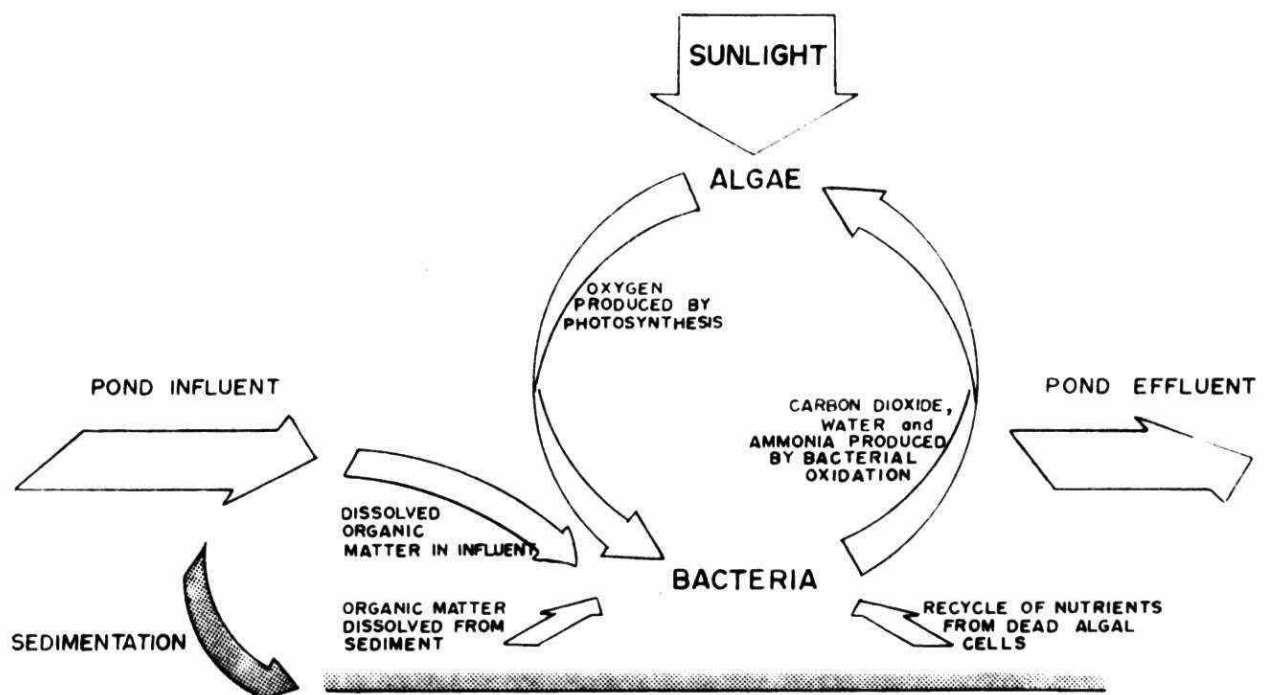


FIGURE 3-15 PROCESSES OCCURRING IN A WASTE STABILIZATION POND including the symbiotic algae - bacteria relationship.

As mentioned previously, cold weather and diminished solar activity in the late fall and early winter reduces the algae and bacterial activity. When the lagoon is ice covered, this activity ceases although some decomposition continues under the ice in the absence of oxygen or under anaerobic conditions. When the ice melts, the gases generated by the anaerobic decomposition process are released to the atmosphere. These gases may become quite offensive, creating odour nuisances in the surrounding area and may persist for periods varying from a few days to several weeks. This is the most critical time of the year in terms of treatment efficiency, difficulty of management and aesthetics.

In some applications, it is necessary to provide storage during the winter months when the lagoon provides a low degree of treatment. This may be accomplished by lowering the water level in the fall of the year when the degree of treatment is high and the streams are in good condition to receive the treated effluent.

DESIGN CRITERIA AND CONSTRUCTION DETAILS

Location

The location of a waste stabilization pond should be based on several factors, namely, cost of land, elevation, prevailing winds, topography, soil characteristics, and proximity and direction of flow in ground water aquifers. The site should be preferably located on the leeward side (downwind) of residential developments in relation to the generally prevailing wind direction and at least 1500 feet from the nearest habitation. In the majority of installations, the elevation of the site has been such that pumping of the sewage flow has been necessary. Soil characteristics should be such so as to produce a minimum percolation into the ground. A seepage rate of over 3/16ths of an inch per day may require artificial sealing of the lagoon bottom. Gravel and limestone formations should be avoided.

Surface Area

Three basic types of operation should be considered in incorporating area into the design:

1. Total retention (no overflow).
2. Intermittent drawdown (based on receiving stream requirements).
3. Continuous overflow.

Fundamental to each type is the maximum loading of the flow and strength equivalent of 100 persons per acre or 20 lbs. of BOD per acre per day. For complete retention, the flow of applied sewage per acre must balance the natural water loss. Considerable data are available on experiences in other states and provinces where higher loadings were utilized with success. However, it is felt that more experience is necessary in this province under the climatic conditions which prevail before the design factor can be refined.

Shape

The overall shape of a waste stabilization pond is not particularly important except as it relates to the surrounding topography. Round, square, or rectangular shapes may be used but care should be taken to ensure that coves, islands or peninsulas are prohibited since they may interfere with circulation and develop local nuisance conditions. Where rectangular shapes are used, the length should not exceed three times the width.

Depth

The optimum depth varies with the season of the year. During the winter season, when the ice thickness may vary from less than one foot to well over three feet, a total depth of five feet is desirable. In the early spring, immediately after the ice has been removed, a shallow depth of about 2.5 feet would encourage rapid algae growth. In the

late spring, summer, and early fall, an intermediate depth of 3 to 4 feet should produce more uniform temperature conditions. Provision should be made in the design of the overflow device for variable level control between a maximum depth of 5 feet to a minimum of 2 feet. At least 3 feet of freeboard should be provided.

Bottom

The pond bottom should be graded level for uniformity of water level control. There should be no obstruction to circulation such as raised inlet pipes, debris, or weed growth when the initial application of sewage is made. Bentonite, asphaltic coating or other suitable material may be used to control the rate of percolation.

Dykes

Compacted embankments of impervious materials should be constructed with a minimum embankment top width of 8 feet. Maximum embankment slopes should not be steeper than 3 horizontal to 1 vertical for both inner and outer walls. The minimum freeboard should be 3 feet plus frost heave. Embankments should be seeded except below the water line. Additional protection for embankments such as rip-rap may be necessary and should be incorporated at the time of initial construction at least along the banks subject to wave action from the prevailing winds.

Inlet Structure

The influent line into single-cell ponds should be essentially center discharging. Influent lines into the primary section of multiple cell ponds should also be center discharging but this does not apply to those cells following the primary cell in series operation.

Either upward or horizontal discharging influent lines may be used where the sewage is pumped to the pond. Horizontal inlets should be used for gravity flow. When upward

discharging lines are used, the discharge end of the pipe should be located approximately 1 foot above the bottom of the pond and should not extend to such elevation that ice will damage the terminal structure during winter operation. The end of the discharge line should rest on a suitable concrete apron with a minimum size of two feet square. Manholes or cleanouts are recommended where the inlet pipe passes through the embankment.

Influent lines should be placed on or under the bottom. The use of exposed dykes carrying influent lines to the center of the pond should be prohibited, as such structures will impede circulation.

Overflow Structure

The location of the outlet near the windward shore should prevent any wind induced short circuiting and permit maximum time-distance between inlet and outlet. Maximum flexibility in stabilization pond operation may be facilitated by incorporating pond level and effluent draw-off level controls in the overflow. An example of such controls is a stop plank support in a manhole for pond level control and an adjustable level intake structure to the manhole.

Multiple Ponds

The use of multiple cells to provide greater flexibility of operation is desirable. Multiple cells permit both series and parallel operation which offers flexibility in handling fluctuating loads such as are experienced in communities that have a large seasonal influx of tourists. It has also been found that erosion due to wind action has been much less on small two-cell installations than at large single pond construction.

Fencing and Signs

The installation of fencing and "No Trespassing" signs is mandatory. The purpose of the signs is to notify persons of the nature of the facility and discourage trespassing.

The minimum requirement for fencing is that it be stock-tight and at least 6 feet high to keep out animals and unauthorized persons.

Pretreatment

Usually, treatment of the raw sewage prior to application to the stabilization pond is omitted. Although some savings in land costs may be realized by reducing the BOD loading to the pond by some means of preliminary treatment, the initial cost of a primary sedimentation unit plus the operating and maintenance costs usually offset any saving.

Normally, chlorination of the pond effluent is not required. However, chlorination treatment is sometimes provided where protection of the receiving waters is necessary during the recreational months.

AERATED LAGOONS

Since the necessary areas may not always be available for the conventional type lagoons, especially for high BOD loads and flows, it may not always be possible to take advantage of the lagoon type of treatment. As a result, consideration has now been given to the supplying of varying proportions of oxygen to such lagoons by mechanical means.

The use of turbine type mechanical aerators, which disperse and mix compressed air into the liquid mass, permits oxygen absorption efficiencies of a much higher order. The major advantage of the aerated lagoon is the continuous oxygen transfer caused by the turbine aerator. In normal oxidation ponds, the algae produce oxygen only in the daylight hours so that sufficient oxygen must be stored during the daylight hours to satisfy the micro-organisms through the night. The continuous oxygen supply of the mechanical aerator, 24 hours a day, permits the aerated lagoon to handle more waste water per day per unit volume.

The surface aerators can be installed on fixed platforms or on floating rafts which are properly anchored. The agitation provided will prevent freezing in cold climates and also keep the pond aerobic even if a portion of the pond is ice covered. The aerator developed by the Infilco Company, known as the "Vortair" aerator, consists of a specially designed turbine located adjacent to the water surface. It pumps up liquid from the bottom of the lagoon and discharges it radially at the surface, creating a so-called peripheral hydraulic jump entraining large quantities of air. Variable speed can be provided to adjust the oxygen input to the particular load.

By the use of artificial aerated lagoons, treatment can be practised with only a four to six day retention time. With solids return from a clarifier following the aerated lagoon, total oxidation type treatment could be practised with a one-day retention period. It is also possible to utilize an aerated lagoon in conjunction with a conventional oxidation pond to obtain the benefits of both systems.

Like all waste treatment systems, the aerated lagoon has certain advantages and disadvantages. It appears to have some value where oxidation ponds are overloaded or where property is expensive. The only maintenance required is periodic lubrication of the aerator motor. There are certain problems to be solved in the use of aerated lagoons for sewage treatment but as installations are constructed, more data will become available and design criteria will be developed.

PUBLIC HEALTH CONSIDERATION

The same precautions which are used in the operation of conventional sewage treatment plants should be practised with waste stabilization ponds. Even though the reduction in bacteria in lagoons is quite high, the possibility of an infection by contact with the sewage should be recognized. Thus, the need for adequate fencing to prevent access by children and animals as well as the posting of signs prohibiting trespassing.

Ground water supplies, particularly those used for municipal purposes, should not be accessible to the seepage from stabilization ponds. Questions have also been raised regarding the possibility of infection being transported by wild fowl which frequent these ponds as well as the infection of livestock by watering in streams receiving lagoon effluent. As yet, no significant data have been established to substantiate these possibilities.

Surveys of mosquito breeding in lagoons in the Dakotas have concluded that production will be of little consequence if weed growths are prevented or eliminated and larvicide is used as required, particularly if difficulty occurs during initial filling.

ECONOMICS OF WASTE STABILIZATION PONDS

The feasibility of waste stabilization ponds depends largely upon the availability of suitable land. Initially, the development of lagoons may have been retarded somewhat because of the belief that land costs could exceed other financial benefits, such as low operation and maintenance costs and the initial capital cost when compared with other treatment methods. Experience has shown that in many cases the price of land may be about 50 per cent of the cost of the completed waste stabilization pond, yet the total cost has been equal to or less than the cost of a completed secondary treatment plant. In numerous instances, land costs could be double or triple the completed lagoon construction costs before equaling the conventional plant cost.

Experience has also shown that in addition to providing advantages of a high degree of treatment, low initial capital cost and low operation and maintenance cost, the waste stabilization pond is quite flexible in areas which are subject to rapid population growth. It has been found that lagoons may be resited and constructed downstream and the pond area which has appreciated in value may then be reclaimed for housing or industrial site development.

In addition to being an economical method of sewage treatment, the waste stabilization pond has been useful in providing a polishing of conventional, primary or secondary treatment plant effluents. There have been a few municipalities in Ontario in which it has been found to be more economical to abandon existing conventional treatment works and construct waste stabilization ponds to handle the entire sewage flow from the community. In these instances, it was not possible to obtain an adequate area for the lagoon at the plant site, but suitable land was found downstream at a reasonable cost.

These factors do not mean that costs are always less for lagoons. Many details such as longer outfall sewers, high pumping costs, high original land costs or difficult construction features may raise costs well above those for the conventional plant. However, a feasibility cost study will indicate the economic advantages of waste stabilization ponds for each installation.

SUMMARY

1. Research and field investigations have definitely proved that waste stabilization ponds are a practical and economical method of sewage treatment.
2. Properly designed and operated stabilization ponds may be expected to provide a degree of treatment comparable to conventional sewage treatment processes.

3. Although stabilization ponds appear to be simple in design and operation, it is essential that the climatic and geographic factors be considered in establishing design criteria.
4. The factors to be considered in site selection for waste stabilization ponds are essentially the same as conventional types of sewage treatment plants.
5. Although there is no evidence to indicate that stabilization ponds constitute a public health hazard, it appears that there are greater potentialities in the propagation of insects and other possible disease vectors than at conventional treatment works.
6. Some of the more common problems are:
 - a) Lagoon inlets and distribution chambers plugging with sand (in sewer systems susceptible to sand infiltration).
 - b) Vandalism causing plugged or blocked pipes or distribution chambers.
 - c) Frozen inlet due to excessive lowering of the liquid level in the cell in preparation for winter operation. (Liquid levels should be maintained at least 12 inches above the inlet pipe).
 - d) Berm erosion due to wave action in large cells.
 - e) Odours resulting from overloading or toxic materials. Odours are likely to occur when ice breakup and spring turnover occurs.
 - f) Excessive growth of weeds if the liquid level is too low.

SUBJECT: 1

SEWAGE TREATMENT
OPERATION

TOPIC: 4

THE ACTIVATED SLUDGE
PROCESS

OBJECTIVES:

The trainee will be able to

1. Describe in general terms the principle of the Activated Sludge Process.
2. Name the three major portions of the Activated Sludge Process.
3. Name three factors which have a major effect on the Activated Sludge Process.
4. Describe using a diagram
 - a) The Conventional Activated Sludge Process
 - b) Contact Stabilization
 - c) Extended Aeration

THE ACTIVATED SLUDGE PROCESS

PRINCIPLE OF PROCESS

After primary treatment, usually by sedimentation and flotation, the treated sewage effluent still contains 60 to 70 per cent of its original organic contaminants. These are in the form of very fine or dissolved organic materials not readily removed by normal mechanical or physical methods. If left untreated, these will cause odours and, eventually, pollution. However, most of this material can be broken down biologically by naturally present bacteria in the presence of oxygen by a reduction process known as biochemical oxidation. Since the primary effluent has insufficient bacteria it is augmented by the addition of an activated sludge which is a mixture of dead biological cell material, small organic solids, and living micro-organisms commonly referred to as *mixed liquor*. It is this solids mass which provides the base to which bacteria cling. These bacteria are known as *aerobic* bacteria.

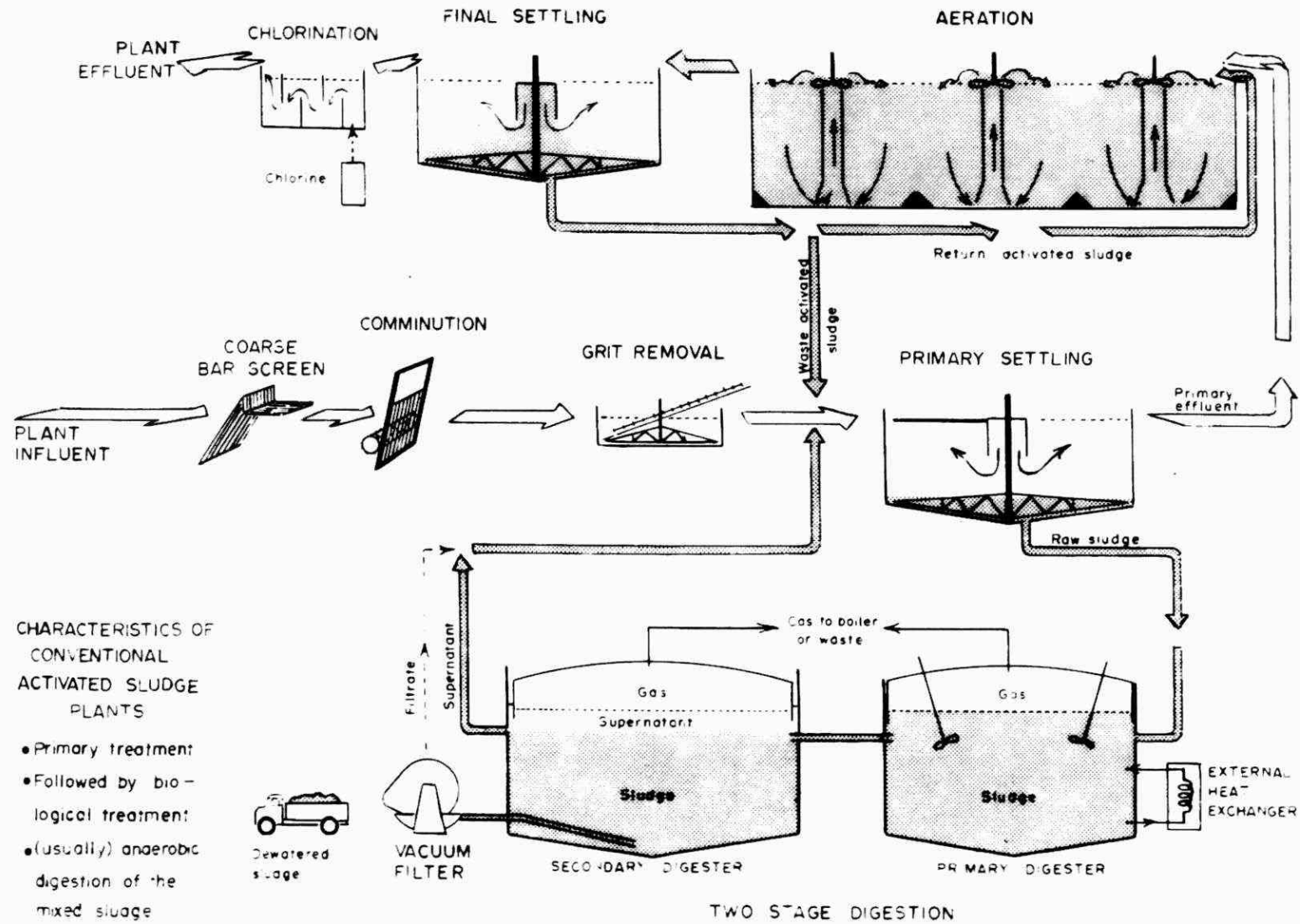
In the presence of oxygen, the bacteria are able to break down the complex organic substances in sewage into simpler organic compounds, which in turn are broken down by different bacteria to nitrates, phosphates, carbon dioxide and water. This is the principle used in the activated sludge process.

The activated sludge process is, therefore, an aerobic process and as such must be supplied with oxygen at all times. Without oxygen, the bacteria will die, the oxidation process will come to a halt and a foul smelling black sludge will be left. In this state, the sludge is said to be *anaerobic* (that is, lacking oxygen). In order to dissolve oxygen into the waste, the activated sludge, the micro-organisms, and the primary effluent are aerated and mixed in an aeration tank. These organisms are then separated from the now treated wastes and settled out in the final clarifier to be recycled and used again. The overflow from this clarifier is a fairly clear liquid which, after

FIGURE No. 4-1

CONVENTIONAL ACTIVATED SLUDGE

Shown here with circular centre-fed clarifiers, mechanical aerators, two stage sludge digestion, and sludge dewatering by vacuum filtration.



disinfection by chlorination, is discharged to a receiving water. (See Figure 4-1).

In summary, the principal elements of the process are aeration tanks, final settling tanks and sludge recirculation.

THE AERATION TANK (See Figures 4-2 and 4-3)

The breakdown of organic materials in the wastewater takes place in the aeration tank. This is achieved by bringing the organic materials into contact with the bacteria in the presence of dissolved oxygen long enough to permit the breakdown to occur. The aeration tanks can be square, rectangular or circular and generally are 10 to 15 feet deep. The tank size depends on the volume of sewage to be treated and its ability to hold the incoming sewage for a period of 4 to 8 hours. The tanks are generally made of concrete or steel, although in some very isolated instances wood has been used. Oxygen is dissolved into the wastewater in tanks either by diffused aeration or surface aeration. *It is essential that adequate mixing is provided, so that the activated sludge is maintained in suspension.*

Diffused Aeration

In this type of aeration system, air is blown from the compressors through various types of devices located at the bottom of the aeration tanks, generally on one or both side walls of the tank. While oxygen is being dissolved into the liquid, a rolling action is generated to ensure thorough mixing and suspension of the activated sludge.

Surface Aeration (Mechanical Aeration)

This technique uses blades of various designs rotating partially submerged at the surface of the liquid with dissolved oxygen from the atmosphere. These devices splash large volumes of liquid over the surface of the tank entraining and dissolving atmospheric oxygen into the tank contents. This also generates pumping action for the necessary mixing.

Figure 4-2 TYPICAL ACTIVATED SLUDGE TANK

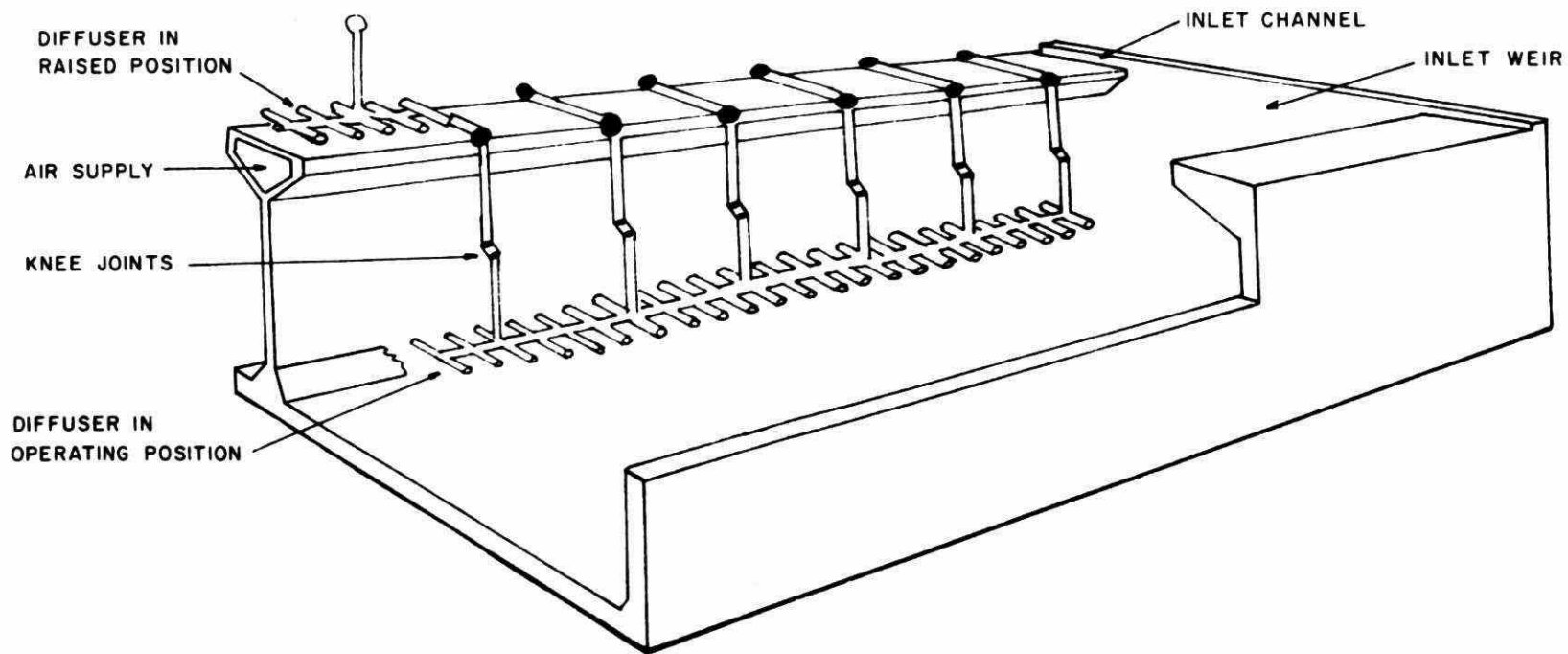
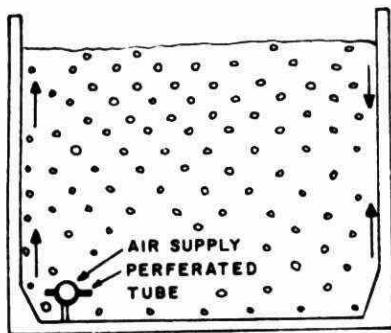
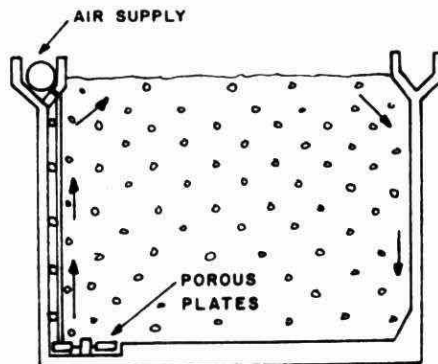


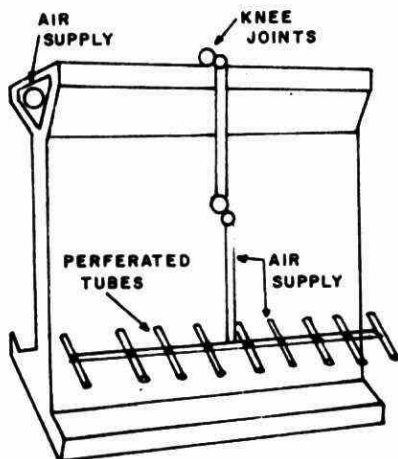
Figure 4-3 AERATING DEVICES



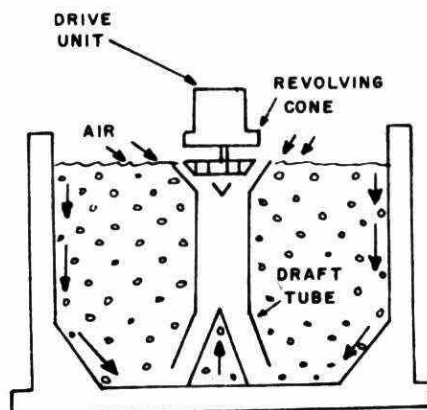
1.
DIFFUSER TUBE
SPIRAL FLOW



2.
POROUS DIFFUSERS
SPIRAL FLOW



3.
SWING DIFFUSER



4.
MECHANICAL AERATOR

The amount of oxygen which can be dissolved varies with the speed of the device, its diameter, submergence, and the horsepower of the drive unit. The drive motor ranges from 5 to 150 horsepower and the device can be as big as 10 feet across.

THE FINAL SETTLING TANK

The secondary clarifier, or final settling tank, receives the activated sludge from the aeration tank. This unit is essential to the activated sludge process since it is here that the micro-organisms are separated from the now purified wastewater. The micro-organisms in the form of sludge (called activated sludge) settle to the bottom of this clarifier where, with the aid of scraper mechanisms, they are collected and returned to the aeration tank to treat more wastewater. The treated wastewater, with only 10 per cent of its original contaminants remaining, flows over weirs to be disinfected before discharge to the receiving rivers or lakes.

FACTORS AFFECTING THE ACTIVATED SLUDGE PROCESS

Since the bacteria do the work in the activated sludge system, the factors affecting the system are those affecting the bacteria. As with all life forms, these organisms can only live if conditions remain suitable for their growth. The following are the main considerations in maintaining activated sludge:

1. Since the bacteria are aerobic, oxygen must be present for the organic materials to be broken down. For satisfactory operation of the activated sludge process, a dissolved oxygen concentration in the aeration tank of at least 1 mg/l should be present at all times.
2. As with all other life forms, a second requirement is food. In this case, the organics in the sewage provide the food supply for the bacteria. The bacteria themselves are the food for some of the higher life forms. Insufficient food will result in cannibalism amongst the bacteria, while an excess causes a shortage of dissolved oxygen and the growth of filamentous bacteria which are undesirable (Figure 4-5).

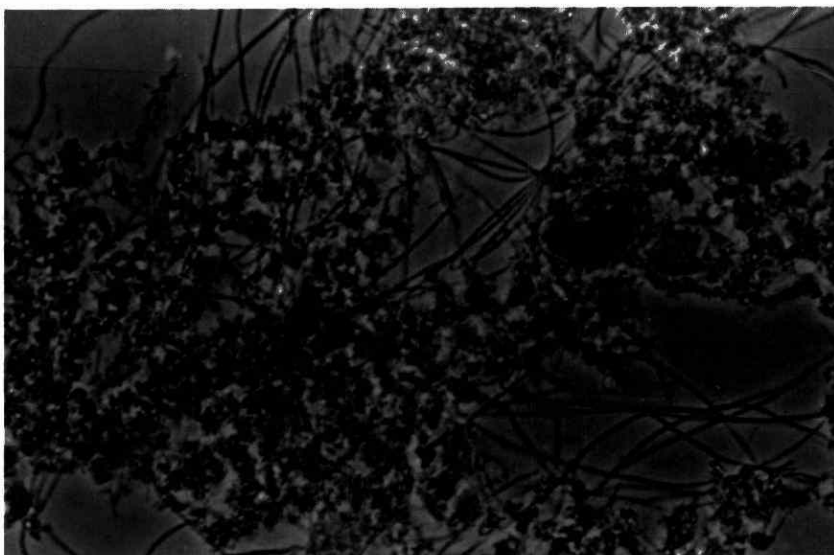


Figure 4 - 4

Filamentous Organisms in Activated Sludge

3. It is also important that sewage entering the activated sludge system contain no materials toxic to microorganisms. The most common source of toxic materials is industrial waste discharge, containing:
 - a. Chemical which result in pH conditions outside the 6.5 to 8.5 range.
 - b. Toxic compounds such as phenol and cyanide.
 - c. Metals such as copper, lead, nickel, chromium, cadmium, etc. in the soluble state.

It is essential that these toxic wastes be eliminated before they enter the activated sludge process. This can be accomplished by:

- a. enforcement of the local Industrial Waste Control Bylaw at the source of the discharge.
- b. pretreatment for removal of the toxic compound at the plant.

Since pretreatment of the total sewage flow to the plant is considerably more costly than eliminating the toxic compound at its source, the bylaw approach is most often taken.

VARIATIONS OF THE CONVENTIONAL ACTIVATED SLUDGE PROCESS

Variations on the conventional activated sludge process include:

1. Extended Aeration
2. Contact Stabilization or Reaeration

Extended Aeration

In the extended aeration process, the aeration tank is larger than in the conventional system and a final clarifier is part of the process. Surplus activated sludge produced is wasted to a holding tank for subsequent removal (Figure 4-5). The average retention times in the aeration units are from 12 to 24 hours. Removal of BOD is very high, and the effluent level is frequently below the 15 milligram/litre objective. However, an ash floc is produced due to the long retention time and the suspended solids content in the effluent from this type of plant is often above the 20 milligram/litre level. An extended aeration plant requires minimum supervision and may be constructed as the ultimate design for this reason, or may be used as an interim process in a conventional activated sludge plant until the loading increases to the point where it can no longer be applied.

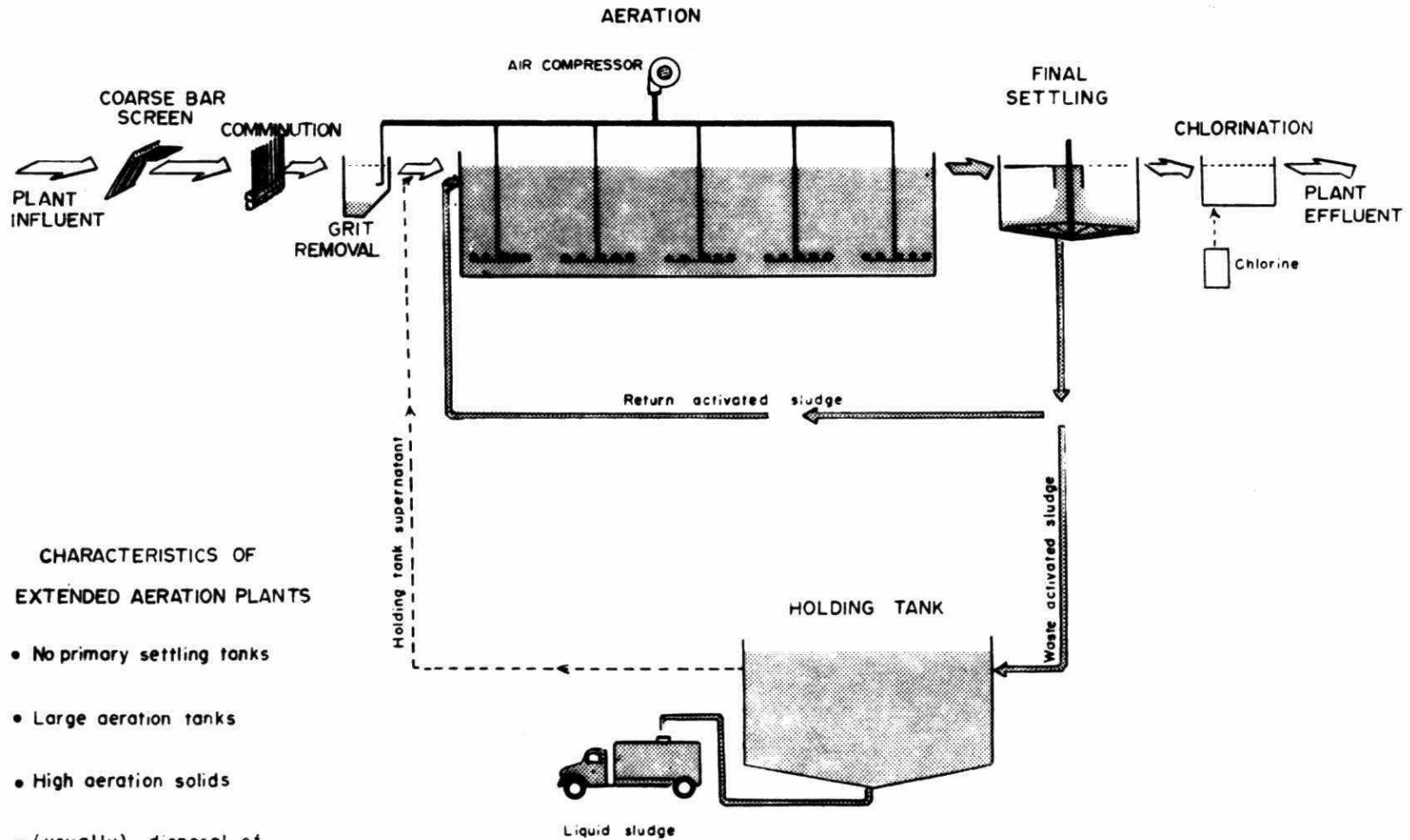
Another form of an extended aeration process which is often used in rural , low density, or fluctuating population areas, is the *oxidation ditch* which is a race track with a surface beater (Figure 4-6). Sludge removal and return is provided, requiring minimum supervision.

The extended aeration process is also applicable in a plant designed and constructed to meet a 20-year goal and having surplus tank capacity in the early years. This is found in the package plant design where the functions of the units can be changed by manipulating certain valves, as the loading on the plant increases through the years. In cases like this, there is usually surplus air capacity available, or space has been provided for its installation when required.

FIGURE No. 4-5

EXTENDED AERATION

Shown here with an aerated grit tank, aeration by diffused air, circular centre-fed clarifier, and a decanted sludge holding tank.



CHARACTERISTICS OF EXTENDED AERATION PLANTS

- No primary settling tanks
- Large aeration tanks
- High aeration solids
- (usually) disposal of raw waste activated sludge.

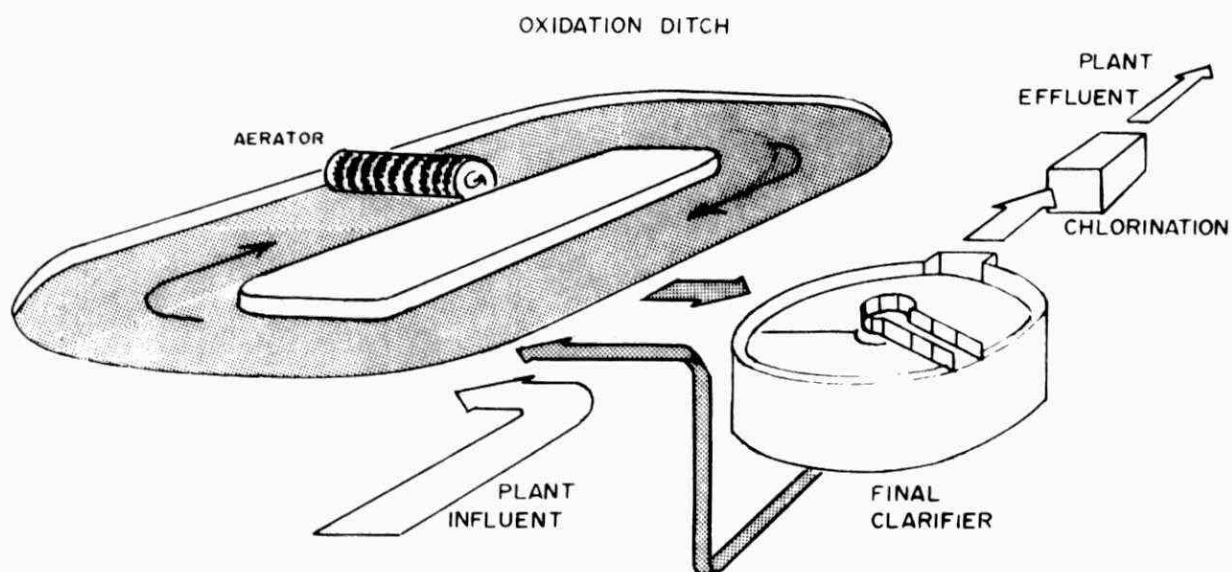
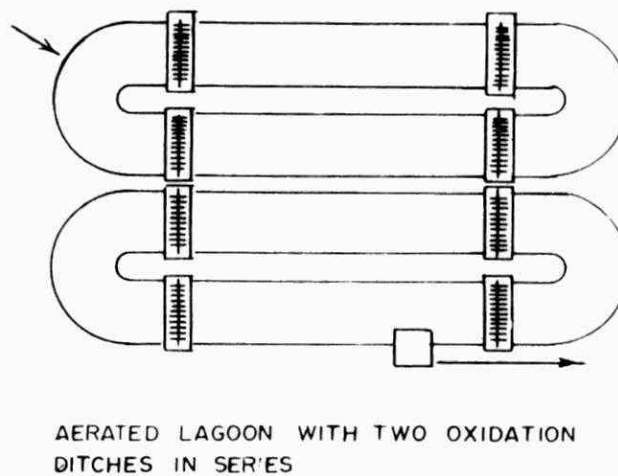
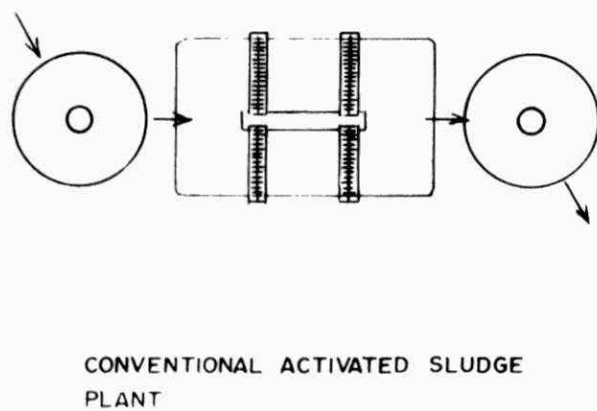
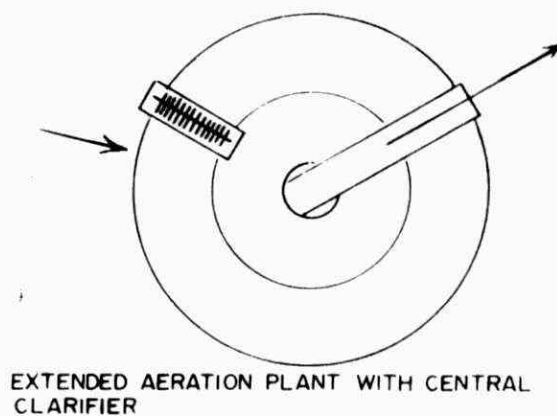
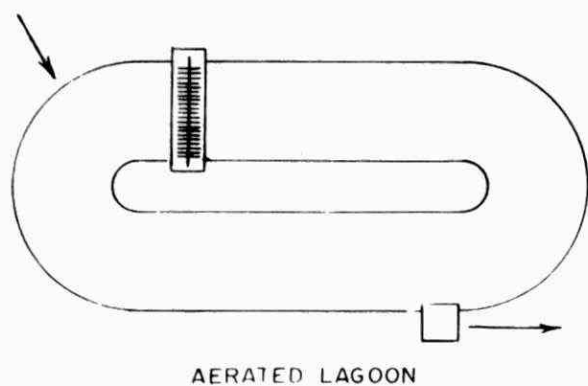


FIGURE No. 4-6 OXIDATION DITCH Shown above as an extended aeration plant.
Other possible configurations are shown below.



Contact Stabilization or Reaeration

Contact stabilization has many patented names and will be considered in its *reaeration* concept.

This process is considerably different from the others. It has smaller aeration units and a larger final clarifier (Figure 4-7). The raw sewage or primary effluent is mixed with the return sludge for 20 minutes to one hour. In this time the activated sludge *adsorbs* the waste particles. The floc produced is not too dense and passes into a larger final clarifier where the activated sludge and its absorbed particles are settled. They are then removed to a reaeration tank where the normal *absorption process* occurs. Because the return flow is only 30% to 50% of total flow, the reaeration tank need only be half the size of the conventional aeration tank. However, the air requirements are at least as much as that of the conventional process, which is more than 1,000 cu. ft. of air per pound of BOD applied. The *reaeration plant* requires high supervision and is hopefully accompanied by low initial construction cost. With the reaeration process, applied BOD is determined (1,000 cu. ft. of air/lb. BOD applied). The required air is divided between the mixed aeration tank and the reaeration tank. Since the retention time in the reaeration tank is approximately 2 hours and the aeration contact time is one hour, the air must be applied to the total system at a high rate.

The process has certain advantages. A considerable amount of activated sludge is held in reserve and if the monitored raw waste varies, the appropriate amount of sludge can be determined for a balanced F/M ratio. There is also some noticeable saving in the size of structures to be built. Its disadvantages include:

1. The need for more pumping and mechanical equipment
2. The pumping of more air into a smaller tank requiring more involved air diffusion.
3. A more competent operator to adjust the process to shock influent loads.

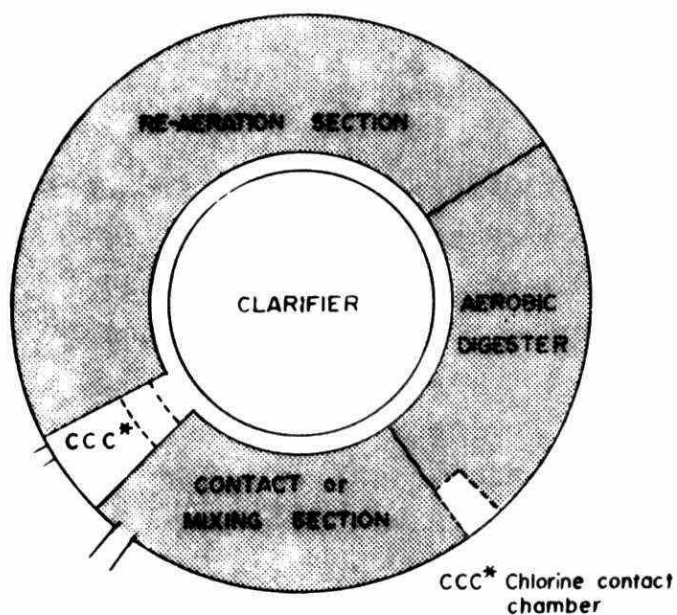


Figure 14a Components are arranged around a central circular clarifier.

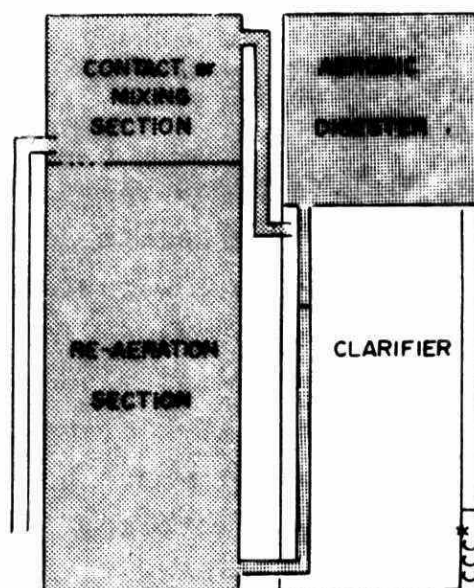
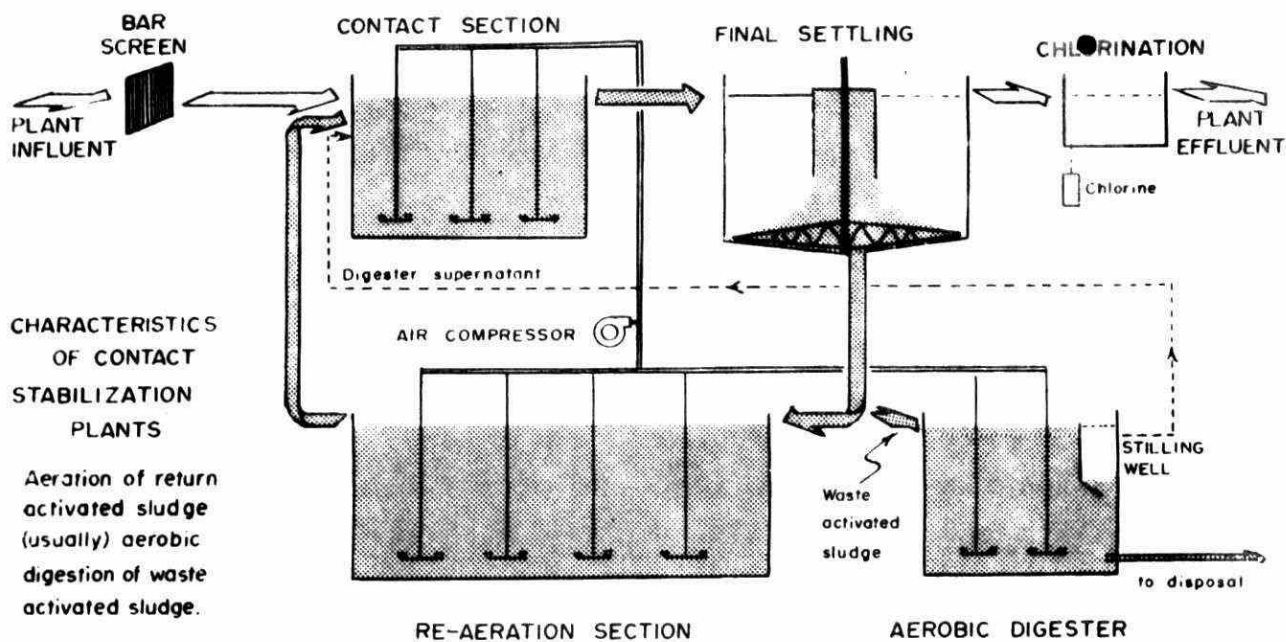


Figure 14b Components are arranged in a rectangular tank.

FIGURE No. 4-7 CONTACT STABILIZATION

Shown here without grit removal facilities since these are not normally supplied as part of the "package".



Factory-built plants frequently provide for these requirements in their design.

PROCESS CONTROL TESTS

To progress from the conventional to the reaeration process, it is necessary to obtain quick information on what is happening. Tests which enable the operator to make quick changes or spot checks on the process efficiency include:

1. *The half hour settling test.* This test gives a complete picture of the process efficiency, especially if it is plotted in 5-minute intervals.
2. Since the available *dissolved oxygen in the mixed liquor* leaving the aeration units can be significant, a good dissolved oxygen meter is a necessity for quick information.
3. Another meter giving good information is a *pH meter*. pH control is a significant requirement in chemical dosing for phosphorus precipitation.

For details of the DO and solids Tests, see Topics 11 and 12.

SUBJECT: 1

SEWAGE TREATMENT
OPERATION

TOPIC: 5

PROBLEMS CAUSED BY
INDUSTRIAL WASTE

OBJECTIVES:

The trainee will be able to

1. List eight features of a sewer-use by-law.
2. List seven causes of problems at the *treatment plant* due to industrial wastes.
3. List six possible causes of problems in *sewers* due to industrial wastes.

PROBLEMS CAUSED BY INDUSTRIAL WASTES IN SEWERS AND SEWAGE PLANTS

GENERAL

Most sewage treatment plants have experienced the problems that can be caused by industrial wastes. In fact, life would be very simple if it were not for the occasional slugs of grease that send personnel scurrying for skimming buckets. Plant operation is easy under ideal operating conditions, but foresight and ingenuity are required to prevent problems, such as those resulting from industrial wastes, without upsetting the entire plant.

SEWER-USE BY-LAW

To control the quality of the waste flows being discharged to the sanitary system, a municipality usually enacts a sewer-use by-law, based on a model by-law published by the Ontario Ministry of the Environment. If the industries comply with this by-law, there should be no problems in the sewers or at the plant. The important features of such a by-law are that discharges must comply with certain standards for

1. Temperature
2. pH
3. Organic loading as measured by the
5-day biochemical oxygen demand (BOD_5)
4. Suspended solids
5. Toxic materials such as
 - a) cyanide as HCN
 - b) phenols
 - c) sulphides as H_2S
 - d) metals
6. Oils and greases or those substances
soluble in ether
 - a) of mineral origin
 - b) of animal or vegetable origin

7. There must be insignificant amounts of explosive, inflammable and/or radioactive materials present.
8. Flow volumes must not result in hydraulic overloading of the system.

The effect of any one industrial discharge on the entire sewage flow will depend on their relative volumes. As most industrial wastes can be treated with domestic sewage in municipal treatment plants, it may be possible for a municipality to accept and treat wastes that do not comply with the by-law limits without upsetting the operation of the sewage treatment plant. The municipality may wish to supply this additional service at no extra charge, or they may require a special agreement with the industry and additional money for this service. Normally, there is a section in the by-law that provides for this agreement. In order that the municipality may decide how to handle any particular situation, they must know the probable effect of any waste flow on their sewers and sewage treatment plant.

An Industrial Point of View

An industry views the treatment and disposal of its wastes as a matter of economics. It expects and deserves treatment of flows within the by-law limits for the normal sewer rate charge. If the municipality will accept a higher strength waste for a sum less than that needed to pretreat the wastes to by-law limits, it is good business for the industry to use this method of disposal. Many times, the full strength waste cannot be treated at the municipal plant. It is then up to the industry to pretreat to a level which is acceptable to the municipality. It is quite often easier to remove contaminants from a waste flow at the source within the industry, and this should be done where possible.

POSSIBLE PROBLEMS

Sewers

The problems that may be anticipated in *sewers* from flows not in compliance with sewer-use by-laws may be outlined under the following headings:

1. Flows - Excessively fluctuating flows may overload the hydraulic capacity of a sewer and cause backing up of sewage into basements, or overflowing at pumping stations.
2. Temperature - The higher the temperature of a waste discharge, the greater the biological activity in the sewer (rate doubles for every 10°C rise). Thus the oxygen supply is quickly depleted and septic conditions occur. Also, high temperatures speed up corrosion and place thermal stresses on the sewer pipes and joints.
3. Suspended Solids - May settle in the sewers and cause blockage.
4. pH - Variance beyond the acceptable limits will result in corrosion of the sewer.
5. Oils and greases will build up on the inside of the lines and reduce the sewer capacity.
6. Dissolved Salts - Certain dissolved salts may precipitate out in the sewers and lead to blockages and/or corroding conditions.

Sewage Treatment Plant

More important, however, is the effect of industrial waste discharges on the operation of the *sewage treatment plant*. First the symptoms must be recognized; then the type and extent of the problem diagnosed and the effect it will have, or has had, on the various processes must be assessed. Finally, and most important, quick remedial action must be taken to offset the changing conditions. Following are comments on characteristics of industrial waste discharges of concern to a sewage plant operator, and relating to the detection and effect on the (a) primary section, (b) biological processes, as well as the corrective action to be taken.

1. Flow - Excessive or surging flow conditions may be noted on the flow measuring devices within the plant or simply by noting the level of the flow on the walls of the channels. High flow rates tend to flush the tanks out, thus affecting the detention times and the treatment provided. Little can be done to ease this condition at the sewage plant; it should be corrected at the industry where the flows may be equalized.
2. Temperature - The rate of biological activity increases with temperature in a waste flow and the resulting septic conditions may be noted by the smell and low dissolved oxygen content of the raw sewage at the plant. A septic sewage will cause septicity in the primary clarifiers and exert an increased oxygen demand in the secondary biological section. The action required in this case would be to pre-aerate or pre-chlorinate the raw sewage flow.
3. pH - A waste with a pH value outside of the accepted range (6.5 - 8.5), besides creating corrosive problems throughout the plant, will tend to reduce the settling and biological processes. This condition may be noted by checking the waste flow with pH paper at regular intervals. Again, little can be done at the plant. The situation should be corrected by having the industry neutralize its wastes before discharge.
4. Organic Loading (Biochemical Oxygen Demand - BOD) High strength industrial discharges will show up in the 5-day BOD test, but this does not help the operating personnel concerned with operating conditions at any given moment. These high strength wastes can usually be spotted by an *unusual colour* (eg. red; indicating blood, dye, etc.), *smell* (eg. a putrid smell because of the rapid depletion of oxygen in the sewer lines) or the inclusion of tell-tale *solids* (feathers, hair, etc.). If the high strength is due mainly to

dissolved components, it will have little effect on the primary treatment process but will create a high oxygen demand and extreme sludge growth in the secondary biological section. If a significant amount of suspended material is included in the high strength waste, additional quantities of sludge will accumulate in the primary tanks and the digesters may be taxed beyond capacity. The action that should be taken at the plant would include carrying a higher concentration of solids and air in the aeration section and the possible addition of alkaline materials to the digesters as well as additional hauling of digested sludge so that a correct environment may be maintained for the anaerobic decomposition process.

5. Suspended Solids - This characteristic of the waste flow is one of the most recognizable. Usually a close examination with the naked eye will reveal unusual conditions which should be taken into account. The majority of the particles in suspension should settle out in the primary settling tanks. While most will be controllable by anaerobic treatment, some particles such as clay, chicken beaks, hair and bark will decompose very slowly, using additional digester capacity. Adjustment in digester operation as well as cleaning of the digesters may be required if these solids are allowed to get through the preliminary screening devices.
6. Toxic Materials - Toxic materials such as copper, chromium, phenols, etc., may be difficult to detect in the raw sewage if they are present in low concentrations. Should either the aerobic or anaerobic biological section be upset, however, laboratory analysis is required to confirm any suspicion in this regard. Higher solids could be carried in the aeration section to help in preventing an upset.

7. Oils and Greases - These ether soluble materials will usually come to the surface in the grit tanks and primary clarifiers, making their presence obvious. If they can be skimmed, either by means of the regular skimming facilities or manually, these materials should be of little concern.

NOTE: *In most cases, sophisticated laboratory equipment is not a necessary part of good sewage plant operation. More important is the ability of the operator to adapt his thinking to the situation at hand and to take proper remedial action.*

Resourceful plant personnel will not only provide good plant operation, but will also note the time and conditions of any upsets at the plant. An attempt should be made to determine the section of the sewer system from which the upsetting discharge came and to define as closely as possible the problem industry. Armed with this information, the municipal officials, after investigating conditions at the industries in the area, should be able to locate the culprit and thus be in a position to enforce their sewer-use by-law.

SUBJECT:

SEWAGE TREATMENT
OPERATION

TOPIC: 6

DIGESTION OF SLUDGE

OBJECTIVES:

The trainee will be able to

1. Explain the main purpose of sludge digestion.
2. Recall two processes employed for the digestion of sludge.
3. List **four** critical factors in sludge digestion.
4. Discuss the factors affecting the operation of
 - a) single stage digestion
 - b) two stage digestion
 - c) aerobic digestion
5. Recall the tests and records required to maintain process control in **single stage digestion**.

DIGESTION OF SLUDGE

PRIMARY PURPOSE

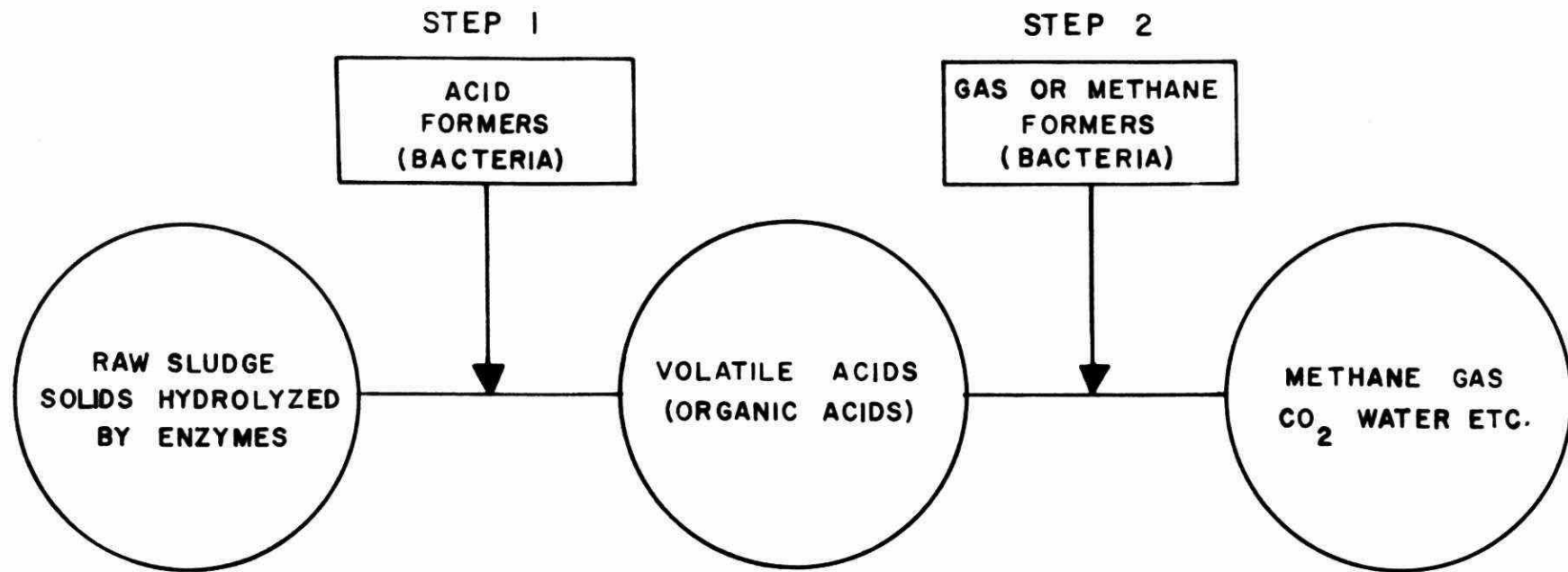
The primary purpose of sludge digestion is to reduce the complex organic matter present in the raw sludge (removed by sedimentation processes) to a simpler non-objectionable state. Digestion produces a sludge more amenable to dewatering, without nuisance, and renders the sludge fit for easy disposal by lagooning, dewatering on sand beds, and by direct application to farm lands, golf courses, parks, etc. Digestion also reduces the volume of sludge and in doing so produces gas which can be utilized for heating purposes or gas engine operation. Sludge digestion can be either anaerobic, described below, or aerobic, described starting on Page 6-22.

THE ANAEROBIC DIGESTION PROCESS

In the anaerobic digestion process, the sludge can be considered as consisting of two portions: a solids portion, composed of material settled in the clarifiers, and a liquid portion, containing materials in actual solution. The concentration of material in true solution is relatively low in raw sludge entering the digester, and is essentially no higher than that contained in sewage entering the treatment plant. Basically, the dissolved materials are the only ones which the bacteria may utilize as food.

After sludge is sent to the digester(s), the organic materials, contained mostly in the solid portion of the sludge, are slowly hydrolyzed and brought into solution by enzymes present in the digester. (See Figure 6-1) Under normal conditions of operation, the organic matter is then quickly broken down into volatile organic acids by a group of bacteria commonly called "acid formers". The organic acids are in turn decomposed into carbon dioxide and methane by a second group of bacteria commonly called the "methane formers". Because of this decomposition, the quantity of

ANAEROBIC DIGESTION PROCESS



FAILURE OF STEP 2 WHILE STEP 1 CONTINUES CREATES AN
EXCESS OF ACIDS REDUCING PH AND FINALLY CAUSING TOTAL
PROCESS FAILURE.

FIGURE 6-1

organic matter actually in solution normally remains low. There is, however, a buildup of certain salts in solution such as ammonium, calcium, and magnesium bicarbonates which result from the breakdown of proteins and soaps. In a digester, these salts produce the natural buffers, which normally remain fairly constant at about 1,000 to 3,000 mg/l as calcium carbonate, depending on the sludge concentration.

When unbalanced digestion conditions exist, the methane-producing organisms cannot remove the volatile acids as quickly as they are formed and a buildup of the volatile acids results. This buildup can take place very rapidly, and in several days the total concentration of the volatile acids in solution can be more than doubled (see Figure 6-1), and note that failure occurs in the critical second phase when the gas methane forming organisms do not break down volatile acids fast enough.

pH ranges from 6.8 to 7.2 have proved effective in maintaining a good digestion process. Experience has shown that digester process failure will be far advanced before the pH will indicate a problem. The volatile acids test has proved more effective in avoiding a process breakdown. Volatile acid concentrations between 200 mg/l and 500 mg/l will indicate satisfactory operation. A change from 300 mg/l to 500 mg/l might indicate a developing problem but until a concentration of 1,000 mg/l is reached, gas production will remain high.

To prevent a drop in pH caused by an excess of acid, alkaline material such as lime or sodium hydroxide may be added to neutralize the excess acids. The continued use of such neutralizers can cause a process failure because of an ion toxicity factor (Na and Ca ions). Therefore, the actual cause of high volatile acids concentrations must be ascertained and corrected for a successful operation.

CRITICAL FACTORS IN SLUDGE DIGESTION

The success of a digester operation and the causes of process failure depend on the following critical factors:

1. Quantity of sludge and digester sizing - overloading or drastic rapid changes in the rate of loading can cause process failure;
2. Quality of sludge - toxic materials such as metal ions can cause a process failure;
3. Temperature - failure in the operation can be caused by a drop in temperature;
4. Mixing - enough space must be provided in the tank for proper mixing.

Quantity of Sludge and Digester Sizing

The quantity of raw sludge will depend upon:

1. The amount and type of solids in the sewage;
2. The removal of solids by the sewage treatment processes;
3. Any change in the amount of solids produced by the treatment processes;
4. The concentration of solids in the sludge to be added to the digestion tanks.

Normally, the suspended solids in a domestic sewage average 0.20 pounds per capita per day. Allowances can be made for industrial waste loadings and figures are available for that purpose.

The removal of suspended solids in the sewage treatment plant varies with the type of sewage treatment and the efficiency of the process as follows:

TABLE 6-1 PERCENT REMOVAL OF SUSPENDED SOLIDS

	<u>Removal Percent</u>
Primary Settling	40-60
High-Rate Trickling Filter	75-85
Conventional Activated Sludge	85-90

The treatment process may increase the amount of solids by conversion of dissolved and colloidal material to settleable solids. Biological processes may reduce the amount of volatile solids by aerobic digestion in trickling filter and activated sludge units.

TABLE 6-2 TEN-STATE STANDARDS OF DIGESTER SIZING

	<u>Cu. ft./Capita</u>	
	<u>Heated</u>	<u>Unheated</u>
Imhoff tanks	--	3 - 4
Primary	2 - 3	4 - 6
Primary + high rate filter	4 - 5	8 - 10
Activated Sludge	4 - 6	8 - 12
Lower digester temperatures require greater volume allowance in the design.		

Table 6-2, which is taken from the Ten-State Standards, gives a simple method of evaluating the loading in cu.ft.per capita of solids directed to a digester. Any drastic change in population and/or the addition of industries requiring water for their process (called "wet" industries) should signal possible problems because of increased loading.

Another loading criteria put forth in the Ten-State Standards, 2 to 3 lbs of solids per month per cu.ft. of digester volume provides space for sludge storage, and supernatant separation, as well as allowing some capacity for overload and a scum blanket.

When only the active digestion volume is considered, new design criteria permit a loading factor of 3 or more pounds of solids each month per cubic foot of digester capacity. The 8 pounds loading factor corresponds

to a ten-day retention period for a sludge of 5% concentration. When using this criteria, only the first mixed-stage of the digestion process is considered. Additional capacity must be added for other factors, such as sludge storage, supernatant separation and overloading.

If the digestion process is compressed into too short a time period, part of the active phase of the process will be transferred to the second stage digestion unit. This will cause supernatant selection and scum blanket problems. Often the second stage digester is not equipped with mixing devices required to control blanket formation.

In smaller installations, the digestion concentrating and storage functions must be effected in one tank. This type of installation is difficult to operate and seldom can all the necessary functions be carried out as effectively as desired.

In any given digester installation there is a limiting loading rate. Any increase in loading due to the development of new industries and/or residential sub-divisions should be noted. Any drastic change in loading rate over a short period of time should also be noted. Even if the system is sized to handle a much higher loading rate, the bacteria in the process must have the necessary time to develop a more active culture.

Quality of Sludge

1. Toxic Wastes

The presence of even trace quantities of heavy metals such as copper can create toxic conditions affecting the rate of digestion. For example, a copper level of 0.5 mg/l in the plant influent can accumulate to a concentration of 125 mg/l in the sludge directed to the digester. While a soluble copper level of 100 mg/l would completely halt the process, part of the copper may be in an insoluble form. This would permit the process to

continue operating, but at a reduced level of activity depending on the concentration actually in a soluble form. Other toxic wastes which can prove to be a problem to the digestion process include chrome and nickel.

2. Grease or Oil

Greases or oils can both overload a system and reduce the active digestion volume by creating an oil or scum blanket. While the additional loading may be a factor, the character of the wastes may also prove to be a problem.

Temperature

The digestion process can be effected in the mesophilic range (10° to 38°C) or the thermophilic range (38° to 60°C). In the colder Canadian climate, the unheated digested temperature may drop to 7°C , at which temperature bacterial activity is very low, so all installations should be equipped with heating devices. Heating can be done by outside circulation of sludge through a heat exchanger or by heating coils in the digester itself. Generally, only the first stage digester in a two-stage operation is heated.

The most favourable temperature for sludge digestion (mainly domestic) is 32°C . Lower temperatures may be used depending on the digester capacity available but some margin of safety should be maintained.

In an underloaded system the required temperature may be calculated by assuming that no digestion takes place at 10°C and a maximum rate of digestion at 32°C . A straight line is drawn to connect the two points to enable the determination of the efficiency of the process; for example, at 27°C the process could be considered to be 75% effective. In calculating temperature requirements include a safety factor to handle overloading and possible furnace breakdown.

When using internal hot water coils for heating, the water feed temperature should be maintained below 54°C. A high temperature will encrust the coils with a sludge cake. Excess water makeup requirements will indicate coil leakage and a smaller than normal temperature drop in the circulation coil water may indicate the formation of an insulation sludge layer on the coils. The use of internal heat exchange coils for digester heating is not recommended on any except small installations.

External Heat Exchangers are preferred because of accessibility for maintenance. These units also provide some mixing and at times the raw sludge feed is directed to the recirculation line to be actively mixed with the circulating "seed" sludge. In a system equipped with good internal mixing this point is to some extent unnecessary.

Mixing

The objectives of mixing or recirculation are:

1. Uniform transfer of heat to entire mass.
2. Intimate mixing of raw sludge with seed sludge mass.
3. Prevention of dead areas and scum blankets.

Many systems have been devised for carrying out the above functions. The most satisfactory results are obtained with digester gas recirculation units or internal mechanical mixers. When these facilities are not available, some mixing is obtained by recirculating digester contents using external pumps. Directing the recirculated sludge to the top of the scum blanket may assist in controlling a scum blanket buildup.

Mechanical mixers can be operated using a timing cycle to attain the required results. In no case should the timing cycle be set with the economic use of power as the only criteria. In an underloaded digester, the mixing units are only operated to prevent the formation of a scum blanket. The draft tube level may be varied to obtain the best results.

The operation of mixers in a single stage digester to provide adequate scum blanket control while obtaining a good supernatant and a concentrated sludge is a problem. Mixing must be discontinued when the supernatant is withdrawn. Therefore, single stage units are to be discouraged.

Where mixing facilities are not provided, alternate means must be developed to remove the scum blanket on a regular basis. Compressed air may be used. For example, a 125 cfm compressor may be used to supply air to mix the contents of the digester and break down the blanket. This should be done at least twice a year and a safety officer should be on hand to ensure that all necessary precautions are taken to prevent a fire or an explosion.

When air mixing is underway the compressor should be located away from the open top of the digester; remove as many of the digester top covers as possible; do not knock steel surfaces together; use non-sparking tools; NO SMOKING should be permitted in the plant area; and the plant gates should be closed to outsiders. The air may be discharged through a one-inch steel pipe (20 feet long) which may be inserted at different points through openings in the top, or the air may be directed through a bottom withdrawal line. It is usually best to remove at least some of the settled solids soon after the mixing is stopped. In difficult cases a new blanket will again form requiring a repeat of the mixing cycle.

With inadequate mixing, a foaming problem may develop. This is caused when a scum blanket commences to digest, thus creating gas. With the blanket being firm the gas bubbles create a foaming condition. This foam may plug gas lines and overflow pipes. The solution to foaming is to reduce the load on the digester and thoroughly mix the digester contents to eliminate the scum blanket. At the same time dilution, pH control, etc. may be required to prevent process failure. This is because a large quantity

of raw or partly digested sludge is added to what may be an already overloaded system.

Gas Production

A gas production of 15 cubic feet per pound of organic solids destroyed can be expected when the digester is operating normally. The gas will contain 65 to 70% methane and 25 to 30% carbon dioxide. During start up and at the time of process failure, the methane percentage will be greatly reduced. The gas yield from an activated sludge plant can be approximately 1.0 cu ft per day per capita. In an average digestion process, approximately 33% of the total solids and 50% of the volatile solids in the raw sludge are reduced by the process. In more volatile sludges the percentage will, of course, be higher.

The quality of gas may be determined by flame colour; also, poor quality gas (low methane content) will not burn in more complex heating equipment. These factors along with daily checks on the quantity of gas produced will assist in pinpointing process problems.

ANAEROBIC DIGESTER START-UP

The following basic procedures are used for anaerobic digester start-up:

1. All construction should be completed before start-up. Alterations and repairs of internal parts are difficult to make once the digester is operating.
2. Fill all lines and tank with water. Raw sewage may be used. Do not use raw sludge as it would overload the process.
3. Add seed material if available. Supernatant or settled sludge from an operating digester is the only product which will be effective.
4. Heat tank contents to 90 to 95°F and maintain at that temperature.

5. Add raw sludge at a rate of .01 pound of solids per cubic foot of digester volume per day for an unseeded digester and a somewhat higher rate, depending on the amount of active material provided, for a well seeded digester. The loading on a high rate process can be .25 pounds of solids per cubic foot per day. The 0.1 pounds of solids per cubic foot per day is equal to 1,000 gallons of 5 per cent sludge to a 50,000 cubic foot capacity digester.
6. Using available mixing facilities, circulate the digester contents and maintain the temperature.
7. Check the process daily by determining the volatile acids and pH. As the volatile acids test is a complex test, it may not be possible to do it as often as desired. As the process proceeds the quality of the gas may be checked if the gas testing equipment is available. Also, the sludge alkalinity may be determined. Lime may be added to control pH but, if the volatile acids approaches 2,000 mg/l, the sludge feed is reduced or stopped as required.

NOTE: Excess lime may inhibit the process.

8. Gradually increase raw solids loading on the basis of favourable trends. The loading must not be increased with volatile acids levels above 1,000 mg/l.

SINGLE STAGE DIGESTION OPERATION

General

Single stage digester operation is covered under four headings:

1. Loading
2. Process Criteria - Mixing, Temperature, Testing
3. Supernatant Selection
4. Digested Sludge Removal

Loading

Ideal conditions would be met if the raw sludge could be pumped continuously to the digester. For various reasons continuous loading is not possible. Small plants receiving eight hours per day of operator supervision may load the digester three times a day, say at eight in the morning, 12 noon, and four in the afternoon. Where automatic pumping facilities are provided the other extreme may be reached with loading being effected once each hour. Where supervision is provided on a 24-hour basis, manual control may dictate six to eight pumping cycles per day. Excess water will be directed to the digester if too many pumping cycles are provided. When raw sludge must be pumped for some distance, to the digester, the sludge line must be filled with dilute sludge before the pump is stopped. The next pumping cycle will direct the dilute sludge to the digester.

In a single stage operation the raw sludge is directed to the top half of the digester. As indicated in the flow diagram appended as Figure 6-2, the raw sludge may be mixed with seed sludge leaving the heat exchanger.

Process Criteria

To maintain the process, two main operating criteria must be met:

SINGLE STAGE DIGESTER

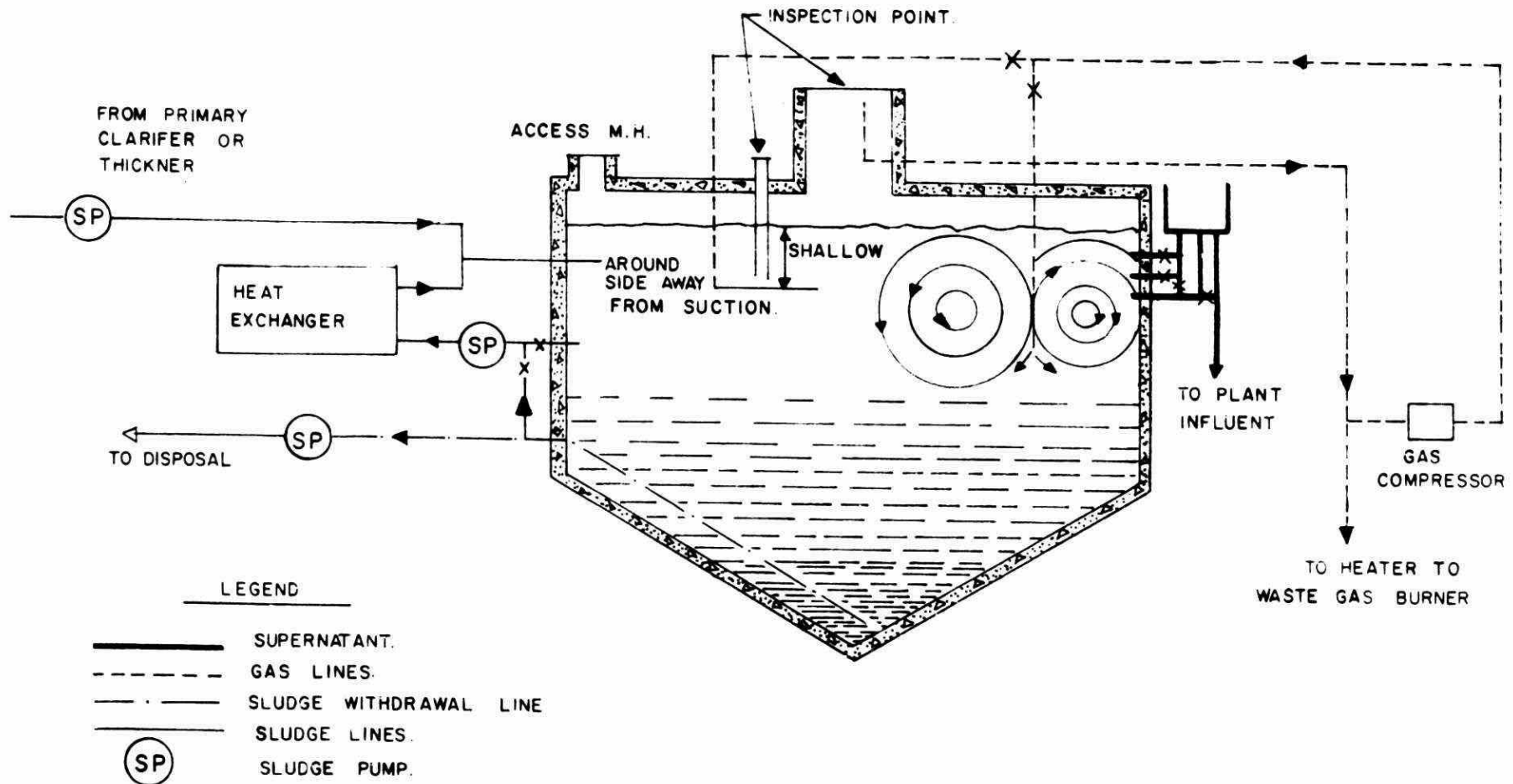


FIGURE 6-2

1. Mixing

Sufficient mixing must be afforded to bring the raw sludge in contact with seed material and also to maintain sufficient area free for the digestion process. Where mechanical or gas recirculation equipment is not available a careful check must be kept on the process to ensure that a foaming condition is not created or that the reaction space left does not become too small. In a single stage unit, mixing facilities, if any, are designed only to mix the material in the top half of the tank. In practice such a design is near impossible. Thus it is difficult to obtain a concentrated sludge from a single stage digester operation.

An improper mixing program could cause a process failure. The active volume available for the digestion process can be greatly reduced by the formation of a scum blanket and sludge banks. Foaming can occur when the scum blanket begins to digest, but may be partly controlled by the use of compressed air to mix the tank contents. When using air for mixing, great care must be taken to ensure that the explosive air-gas mixture is not ignited. This control measure may be required two or three times a year depending on need. *Be careful* when using air to mix the digester contents. Obtain the services of a safety officer. Forbid smoking in plant area, use rubber footwear, using no-sparking tools and do not bang pipe so as to cause a spark at digester openings. Also, open as many manholes as possible for ventilation.

2. Temperature

The second process criteria that must be considered is temperature. The ideal operating temperature for mesophilic digestion is between 32-35°C. A lower temperature may be used if excess digester capacity is available.

3. Tests and Records

To maintain a check on the process, various tests and records are required. The number of tests required or that can be economically performed at a plant will greatly depend on the equipment available and the size of the plant. Also where good mixing is afforded the chance of process failure is less; and therefore fewer tests would be required. A few of the tests, *listed in order of importance*, are as follows:

- a) volatile acids,
- b) temperature,
- c) scum blanket depth,
- d) supernatant suspended solids,
- e) pH,
- f) alkalinity,
- g) gas compositions,
- h) raw and treated sludge composition,
volatile and total solids.

Records can also be kept of:

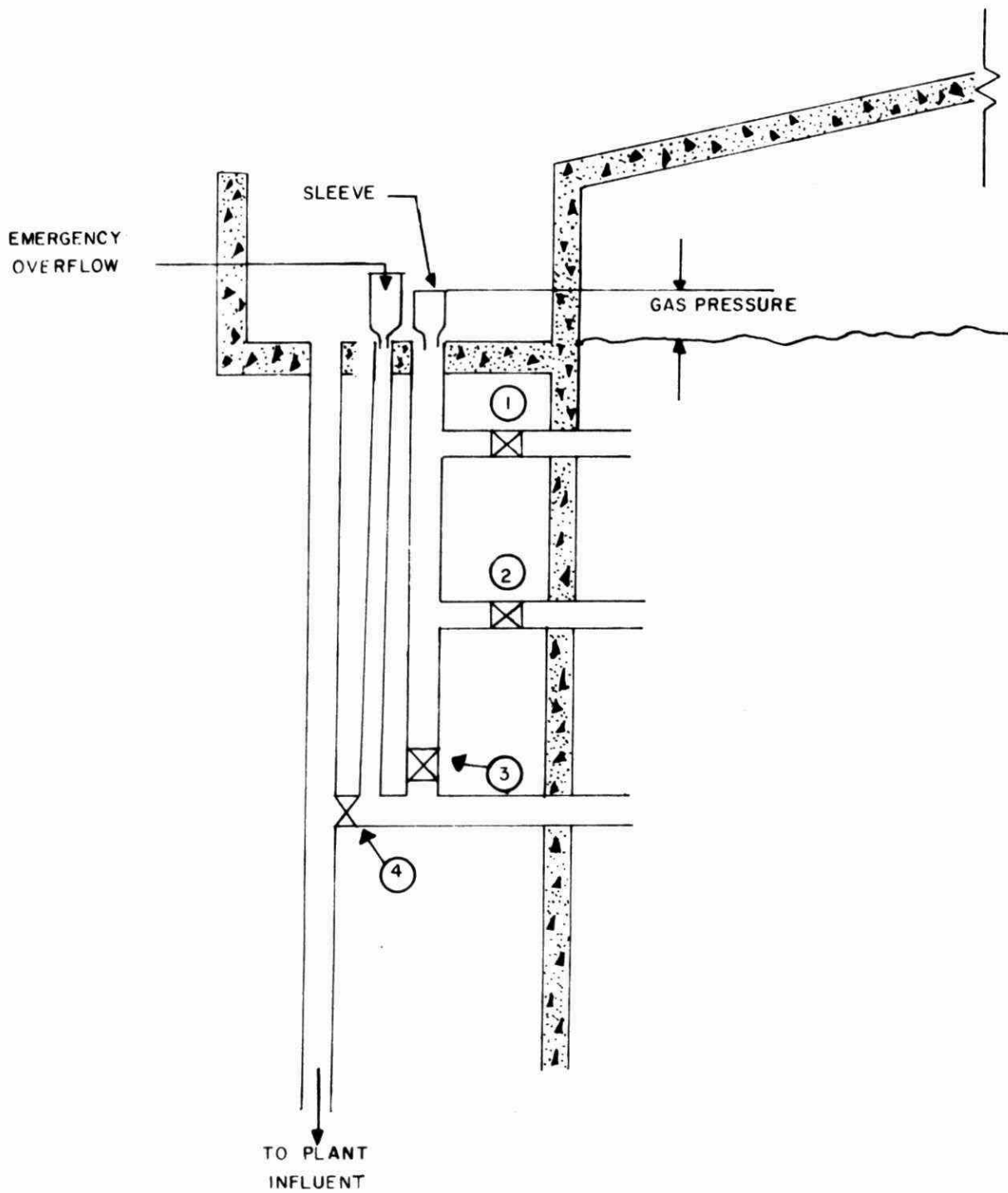
sludge directed to digester,
sludge removed from digester,
quantity of gas,
mixer operating schedule.

Supernatant Selection

It is difficult to obtain a good supernatant from a single stage digester. Nevertheless, an attempt should be made to remove excess liquid. Where mechanical mixing is practised, the mixing devices are shut off for a period of time before the supernatant is withdrawn. Experience will show the quiescent period required to obtain a good supernatant.

When a variable level supernatant selection is provided the supernatant is removed via the line proving to be most satisfactory. An example of a supernatant selector system is appended as Figure 6-3. Withdrawal control is maintained in simpler installations by a sleeve height adjustment. Other installations use valves to control the withdrawal process. In all installations a safety overflow should be kept open at all times.

FIGURE 6-3



SUPERNATANT SELECTOR

The suspended solids test is used to check on the efficiency of the withdrawal process. The actual test can be determined using a centrifuge for quick results, and the standard suspended solids test where complete laboratory equipment is available. The raw sludge directed to the digester may have a suspended solids concentration of 30,000 to 60,000 mg/l. Therefore, the supernatant suspended solids concentration should not be allowed to approach plant operation. A suspended solids concentration of 1,000 to 3,000 might be considered permissible with the ideal level being below 500 mg/l.

Digested Sludge Removal

The accumulated sludge should be removed as frequently as possible. It will be difficult to obtain a concentrated sludge from a single stage operation. A 3% to 4% sludge may be considered good for the digested sludge obtained from an activated sludge plant utilizing a single stage digestion process.

When the gas is utilized from a fixed cover operation, the digested sludge is best removed when the raw sludge is being pumped. This practice will assist in maintaining the gas pressure.

Bottom withdrawal line and depth samples are tested to control the sludge withdrawal process. The total and volatile solids tests are two criteria used to evaluate the stability of the sludge and its concentration.

TWO STAGE DIGESTION

General

Two stage digestion is covered under five headings:

1. Loading
2. Process Criteria
3. Sludge Transfer
4. Supernatant Selection
5. Digested Sludge Removal

Loading

When high rate complete mixing is practised the raw sludge may be directed to any point in the first stage tank. Otherwise the loading procedure is similar to that used for the single stage operation.

A good two stage design will allow the use of either tank for the first stage or heated unit. An example of a two stage digester flow diagram is given as appended Figure 6-4.

Process Criteria

1. Mixing

Where mixing devices are available they are operated to control scum blankets and inactive dead spaces. Most of the mixing is effected in the first stage tanks. Often mixing units are not installed in the second stage tank. The mixing devices may be operated either full or part time. When part time operation is desired the cycle is set up in relation to tests and observations of scum blanket formation and not on power saving. In some operations the mixers may only be used a few hours a day.

An improper mixing program could cause a process failure. The active volume available for the digestion process can be greatly reduced by the formation of a scum blanket and sludge banks. Foaming can occur when the scum blanket begins to digest. The scum blanket may be partly controlled by the use of compressed air to mix the tank contents. When using air for mixing great care must be taken to ensure that the explosive air-gas mixture is not ignited. This control measure may be required two or three times a year depending on need. Be careful when using air to mix the digester contents. Obtain the services of a safety officer. Forbid smoking in plant area, use rubber footwear, use no-sparking tools and do not bang pipe so as to cause a spark at digester openings. Also, open as many manholes as possible for ventilation.

TWO STAGE DIGESTER

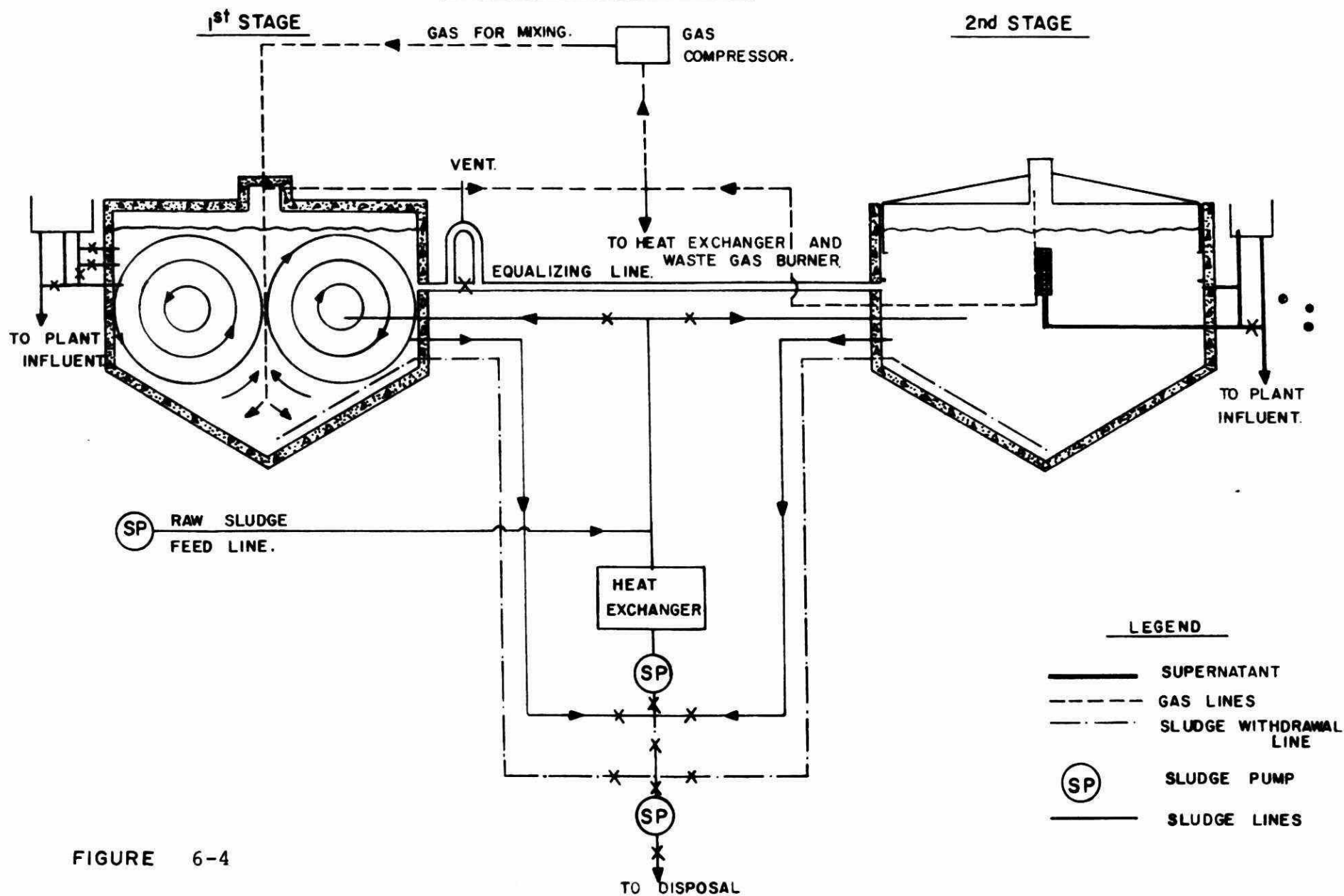


FIGURE 6-4

2. Temperature

Heating units are used to heat the contents of the first stage digestion tank. Optimum mesophilic digestion is carried out at between 32°C and 35°C. However, lower temperatures may be used where excess digester capacity is available. The maintained temperature should be such as to provide some safety factor.

Sludge Transfer

Sludge can be transferred from the first stage digester by a number of means, three of which are as follows:

1. Automatic transfer may be effected using an equalizing line, as shown on Figure 6-4.
2. Sludge may be transferred using the heat exchange unit recirculating line.
3. Bottom sludge may be pumped to the second stage unit.

The transfer program should be set up to delay the removal of solids from the first stage unit. If possible, top material is transferred when the mixing devices are off. Nevertheless frequent transfers, at least once a week, must be made from the bottom of the first stage tanks. If this is not done the bottom withdrawal line will plug with grit and solids.

Supernatant Selection

The supernatant is obtained from the second stage digester. The supernatant can be selected automatically when a sludge transfer takes place or as an operating procedure when the plant can best receive the extra BOD loading. The type of selectors provided will of necessity partly dictate the program to be chosen.

Digested Sludge Removal

In a fixed cover installation the sludge must be removed in small batches. If this is not done the gas pressure will not be maintained.

When at least one floating cover is provided the sludge settled in the second stage unit may be removed as convenience requires; large withdrawals will not cause process failure or a loss of gas pressure.

Sludge samples should be collected as indicated for the single stage operation. A two stage operation will provide a more concentrated sludge.

THE AEROBIC DIGESTION PROCESS

General

The aerobic digestion process is an extension of the extended aeration process where the volatile material in the wastes is destroyed to a reasonable maximum with up to a 45% destruction of volatile solids. The aerobic digester is a separate operation in which concentrated sludge, having 3-6% Mixed Liquor Suspended Solids is processed. The decomposition of solids and regrowth of organisms is maintained until the available energy in active cells and the storage of waste materials are sufficiently low and stable enough for disposal.

CRITICAL FACTORS IN PROCESS

The aerobic digestion system is simple to operate and maintain when compared to the anaerobic digestion process. While the operator may have little control over the discussed design factors, he should be aware of system limitations if he is to effectively manage the system he is responsible for and encourage improvements.

The most critical factors include:

1. Air supply
2. Volume of system
3. Tank insulation

Air Supply

An air supply of 20 cu. ft/min. per 1,000 cu. ft. of digestion tank volume was originally suggested for aerobic digestion. This level of air feed, however, has not proven to be effective in keeping solids in suspension and maintaining a 1 mg/l oxygen level in the digesters. It is now suggested that the air supply should approach 50 cu. ft/min. per 1,000 cu. ft. of tank volume. In a conventional activated sludge plant, this air supply would be nearly twice the amount of air required in the aeration tanks.

Volume of System

The system is sized to maintain a minimum sludge age of 45 days. If complete stabilization is desired, the total sludge age could be as high as 120 days. In using the 120 day criteria the sludge age in the regular plant itself may be added to the sludge age of the aerobic digesters. An aerobic digester system having a sludge age design factor of 45 days would have a tank volume equal to the volume of the conventional aeration tanks sized to provide 8-hour detention. Since the MLSS may be maintained at a 3-6% level in the second stage of a two-stage system a small volume is possible with the two-staged unit.

Tank Insulation

In the colder Canadian climate, steps should be taken to retain the heat in the aeration tanks. For this reason open steel tanks built above ground are not recommended. To reduce heat loss, a common wall construction with existing tanks in the plant and earth filling around the remaining walls is recommended. Additionally, long above-ground air pipes should be insulated.

OPERATION AEROBIC DIGESTER SYSTEM

Operating procedures for the aerobic digester system will be considered as follows:

1. System start up
2. Sludge feed program
3. Supernatant control
4. Transfer program
5. Processed sludge removal
6. Air control and records
7. Scum control

System Start Up

Fill the first aerobic digester tank within three feet of the top with water (use primary or plant effluent or clear water, *not sludge*). Add seed activated sludge from return sludge flow. Pump raw sludge from primary. Maintain the dissolved oxygen level at 1.0 mg/l (or more).

Each day shut off the air system to allow the solids to settle; decant the supernatant to the plant influent.

Continue to pump in sludge from the plant. Excess activated sludge should be wasted to the primary clarifier two hours before pumping is undertaken (this directs fresh activated sludge to digester). Where there is no primary clarifier, the excess sludge is wasted directly to the digester.

When solids have reached a MLSS level of 10,000 to 15,000 mg/l, the sludge settles to approximately 50% of tank volume. Fill the second stage aerobic digester tank to within three feet of top with primary or secondary effluent, then transfer sludge from the bottom of the first stage digester to the second stage tank. Decant the supernatant as required to maintain capacity for additional loading.

Sludge Feed

Pump sludge to the first stage digester according to the established plant program. If the plant has a primary clarifier, the waste MLSS should be directed to the primary clarifier two hours before the sludge pumping cycle begins. Sludge cannot be pumped when the digester is in the supernatant removal phase. Also, a plant not equipped with a primary clarifier must pump excess return activated sludge directly to the digester.

Supernatant Control

Shut down the air supply to allow the MLSS to settle. The time required will depend on the settleability of the solids. Then draw off supernatant from a point below the surface. The shut-down time should be short to eliminate possible problems.

Transfer Program (2 and 3 stage systems)

Sludge is concentrated and transferred as required from the bottom of the first stage unit to the second stage unit. This transfer is not necessarily done each day.

Remove sufficient supernatant from the second stage tank to allow the transfer to proceed. In a three-stage system, the first stage air supply is seldom shut down. Therefore, the supernatant is only removed from the final two stages.

Processed Sludge Removal

The processed sludge is removed from the bottom of the final stage for land disposal with tank trucks or it is directed to sandbeds or sludge lagoons in isolated small plant operations.

Air Control

Sufficient air must be delivered to keep solids in suspension and a minimum oxygen level of 1.0 mg/l in all tanks.

Scum Control

Excess scum should be removed manually from the surface of the tanks on a regular basis.

Records

Records can be kept of sludge directed to the system and sludge removal. A centrifuge should be used to determine sludge concentrations in the raw feed, in each tank, the digested sludge and the supernatant. Laboratory tests, mixed liquor suspended solids (MLSS) and volatile solids should be obtained as required to check the process operation.

SUBJECT:

SEWAGE TREATMENT
OPERATION

TOPIC: 7

SLUDGE HANDLING METHODS

OBJECTIVES:

The trainee will be able to

1. Define sludge and name its sources in the waste treatment process.
2. List the concentration of solids (in per cent) expected in:
 - a) raw primary sludge
 - b) waste activated sludge
3. List three factors which determine the quantities of sludge produced.
4. Describe four methods used to dewater sludge.
5. List five factors that influence the selection and use of chemicals for flocculation.
6. Discuss the methods of final sludge disposal.

SLUDGE HANDLING

GENERAL

What is sludge? Sludge is the residue resulting from the removal of dissolved or suspended material during the treatment of water and wastewater. Sludges are usually identified in terms of the treatment process in which they originate, e.g. raw sludges from primary sedimentation, digested sludges from aerobic and anaerobic digesters.

CONSIDERATIONS IN SLUDGE HANDLING

Sludge Concentration

Sludge concentration is defined as the reduction in moisture content of a sludge in order to decrease sludge volume while still maintaining its fluid properties. By this definition, sludge dewatering is excluded because the purpose of dewatering is to reduce the liquid sludge to a relatively dry cake. To a limited extent, sludge concentration occurs in most clarifier operations; however, this is not the purpose of the clarifier and the concentration of solids in sludge is best carried out in a separate unit.

It must be remembered that if there is initially less water in a sludge then the disposal of this sludge will be less costly. When trying to concentrate sludge in the clarifier one must remember that most pumps are not designed to carry sludge which has total solids concentrations of greater than 10 per cent. Waste activated sludges characteristically have concentrations of only 0.5 to 1 per cent (%). A reduction in volume by concentrating to 3-4 per cent (%) would be significant. Such sludges are quite fluid and easily pumped. Raw primary sludges normally have concentrations of 5 per cent or higher.

Sludge Quantities

It is necessary to know the amount of sludge that can be produced at a sewage treatment plant for design requirements, budget requirements and for process control and efficiency. The volume of sludge that is produced is dependent on a number of factors, three of which are listed below:

1. Raw sewage strength and quantity
2. Type and degree of treatment provided
3. Type and degree of sludge treatment

The sewage strength is normally measured in terms of BOD and suspended solids concentrations. These measurements can be affected by such parameters as the type of industries on the sewage system, the degree of infiltration into sewers, and the consumption of water per capita. For a normal domestic waste, the loading on a plant can be estimated by allowing 0.17 pounds BOD and 0.20 pounds suspended solids per capita per day.

The degree of treatment that a sewage treatment provides will affect the quantity of sludge produced. The following table lists the removals expected at various types of plants:

TABLE 7-1 EXPECTED REMOVALS

TYPE OF PLANT	BOD ₅	S.S.
Primary Sedimentation	30-60%	50-60%
Single Stage Low Rate Trickling Filter	80-90%	80-90%
Conventional Activated Sludge	85-95%	85-95%

For the purpose of this topic and without considering the more exotic forms of sludge treatment, sludge is considered to be either digested or raw. The volatile solids content of the sludge can range from 60 to 85%. As a general rule, digestion provides for approximately a 40 to 60% destruction of the volatile solids but this percentage can be higher. This destruction, of course, is dependent on such factors as mixing, temperature, detention time, and the initial volatile solids content of the sludge.

One should note that in a conventional activated sludge, excess (or waste) sludge is produced and must be disposed of. The quantities generated depend, in part, on a relationship between the oxygen available, the concentration of organisms and the organic load.

Sludge Withdrawal

Raw sludge withdrawal should consist of a sludge as dense as possible, preferably in the range of 5 to 7 per cent total solids. The settling tank hoppers should be cleared as thoroughly as possible without drawing liquid. Sludge may be removed by hydro-static pressure in some installations or by pumping. The manner in which sludge is removed has a great effect on both the settling tank and the digester.

It is generally better to remove sludge three to four times a day and provide a more constant food supply to the organisms doing the work, than to remove all of the daily sludge accumulated at one time. If too little sludge is removed, the clarifier effluent will deteriorate. If too much is removed, the digester operation will deteriorate and extra supernatant must be treated. See Examples 1 and 2.

A constantly watery sludge would indicate that too much sludge is being pumped; eg. the sludge concentration in the digester is not allowed to increase. If a thick sludge is being pumped at the beginning of the pumping cycle

and turns watery towards the end, the pumping rate is too high. In this case, the volume of sludge entering the pit or hopper is not as great as the amount being pumped out of it. Since the pumping rate is not easily adjustable, the length of the pumping cycle should be decreased and the pumping frequency increased. At a primary treatment plant, a general guide would be to pump approximately 3,000 gallons of sludge per million gallons of raw sewage treated; the exact amount to be pumped will depend on local conditions. Gas bubbles and pads of black sludge on the surface are an indication that the settled sludge is becoming anaerobic. In this case, the frequency and the amount pumped should be increased to remove the sludge more quickly and thus prevent these conditions. If the sludge is particularly difficult to pump even though there is little sludge in the tank, check the volatile solids. If they are less than 50%, this probably indicates that an excessive amount of grit has found its way into the clarifier. A more frequent cleaning of the grit facilities should rectify this.

EXAMPLE 1

GALLONS OF RAW SLUDGE TO BE REMOVED (Figure 7-1) (Based on Following Parameters)

1. 5% Total Solids
2. 60% Removal of Suspended Solids

Curve A: influent s.s. - 250 ppm
(effluent s.s. - 100 ppm)

Curve B: influent s.s. - 200 ppm
(effluent s.s. - 80 ppm)

Curve C: influent s.s. - 150 ppm
(effluent s.s. - 60 ppm)

Curve D: See NOTE below

The operator should now compare his sludge pump capacity with the amount to be removed and arrive at a figure for timing his sludge removal to prevent removal difficulties noted elsewhere.

NOTE:

For actual removals, the spacing of the curves on the graph change as follows (see Curve D Figure 7-1)

Assume inlet s.s. - 200 ppm
(measured in lab)

Assume outlet s.s. - 120 ppm
(measured in lab)

Therefore removal is 40% = 80 ppm

EXAMPLE 2

GALLONS OF DIGESTED SLUDGE TO BE HAULED

DIGESTED SLUDGE

Assuming that the following waste characteristics are received at a primary treatment plant calculate sludge quantities at various stages:

Type of waste - domestic sewage
Flow - 2.2 MGD
S.S. - 200 mg/l (ppm)

Assuming 50% removal of suspended solids,
we have:

$$\frac{50}{100} \times 200 \text{ ppm} \times 2.2 \text{ MGD} \times 10 \text{ lb/gal} \\ = 2200 \text{ lbs dry solids/day removed to the digester.}$$

In terms of a 6% liquid, digested sludge where the total solids reduction is 35% and the supernatant is decanted off we have:

$$2200 \times \frac{100}{6} \times \frac{1}{10} \times \frac{100 - 35}{100} \\ = 2400 \text{ gal/day to be hauled.}$$

PRIMARY SLUDGE REMOVAL

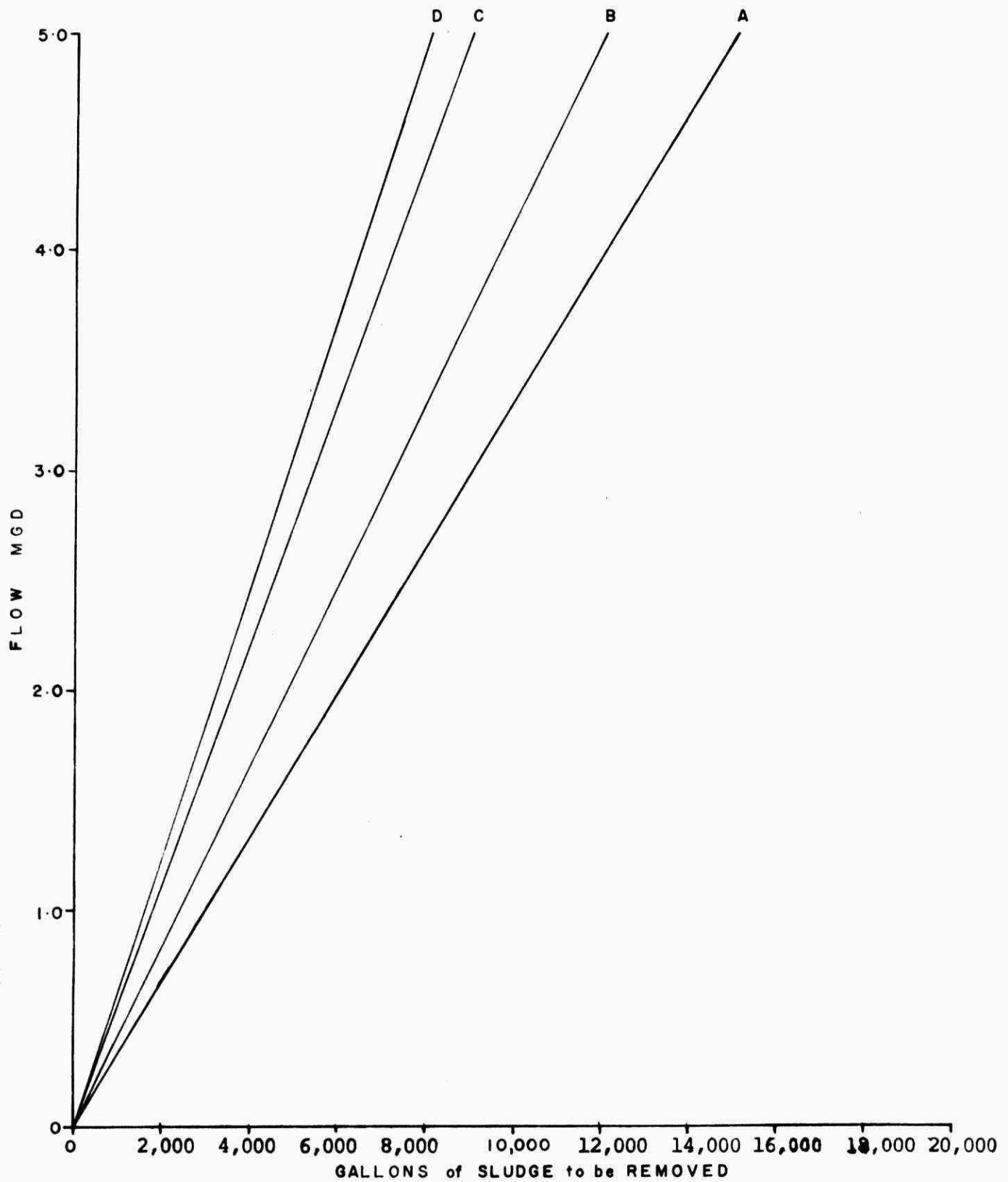


Figure 7-1

Therefore amount of sludge to be pumped at 1 MG
plant flow rate and 5% solids

$$= 80 \times \frac{100}{5} = 1600 \text{ gallons}$$

Therefore amount to be pumped at 5 MGD = 8000 gallons

FORMULA

If influent s.s. = A ppm

and effluent s.s. = B ppm

Therefore amount removed = (A - B) ppm

Therefore gallons of sludge to be pumped at flow rate of
1 MGD through primary section and at Q% total solids

$$= \frac{(A - B) \times 100}{Q} = G \text{ (gallons of sludge to be removed)}$$

(Where flow rates differ from 1 MGD multiply "G" by
appropriate fraction of 1 MGD.)

CONDITIONING OF SLUDGES

Use of Chemicals

Prior to being dewatered, most sludges must be pre-conditioned or flocculated using chemicals. When flocculation occurs, the solid particles are agglomerated in the liquid and the liquid is withdrawn by vacuum while the solids are deposited on the filter media.

The chemicals used for flocculation vary; however, the most commonly used chemicals are polyelectrolyte (polymers), ferric chloride and lime. The amount and type of chemical used will depend on the sludge to be filtered. Several factors influence the chemical demand:

1. Sludge Concentration
2. Type of Sludge
3. Size, Shape, Density and Charge of Solid Particle
4. Compressibility of Solid Particles
5. Viscosity of Filtrate
6. Alkalinity (Chemical Composition)

Sludge concentration is a critical factor.

Increasing the solids concentration will increase the filter yield. The more concentrated the sludge, the less filtrate has to be removed per pound of filter cake deposited. Concentration also lessens the liquid demand, and, hence, lowers the amount of chemical coagulation required. Since activated sludge is thin (usually less than 1% total solids) the chemical demand for this type will be much higher than a concentrated primary sludge (6-10% total solids).

The second most important factor is alkalinity. If alkalinity is reduced, the chemical demands are reduced. One process which reduces alkalinity is *elutriation*.

Basically, elutriation is a solids washing process. An elutriated sludge is one that has had the alkalinity of its water reduced by dilution, sedimentation, and decantation in water of much lower alkalinity.

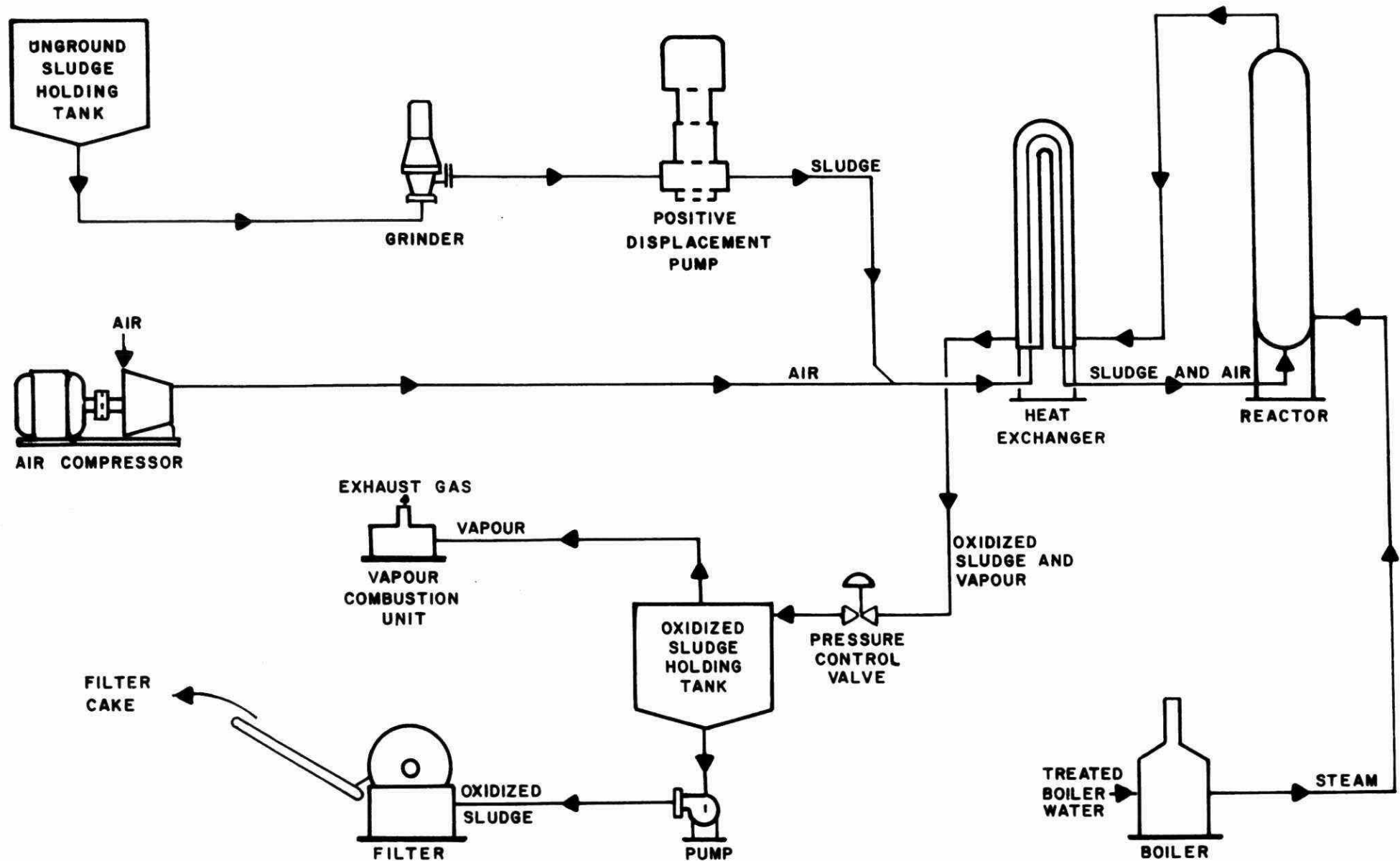
One important point that must be noted is that no two sludges have the same characteristics. If for some reason one particular type of chemical works well in one operation, it will not necessarily work for another.

Wet Air Oxidation

The Wet Air Oxidation process converts the sewage sludge structure to one that is easily dewatered. Hence, the sludge solids may be separated from the liquid portion of the sludge by settling in Decant Tanks and then dewatered to 65% moisture content on Vacuum Filters. The resulting filter cake is sterile and may be disposed of on land or by other convenient methods.

In the Wet Air Oxidation process, raw primary, waste activated and digested sludges or combinations thereof are heated with air to a reaction temperature of approximately 180°C for 15 minutes. The pressure of the incoming sludge is increased by the use of high pressure sludge pumps and

Figure 7-2 WET OXIDATION PROCESS
THERMAL SLUDGE CONDITIONING AND DEWATERING



high pressure air injected into the system immediately downstream of the high pressure sludge pumps. The pressure in the system is increased as required to approximately 320 p.s.i.g., to raise the boiling point of the water in the sludges in order that oxidation may occur in the presence of water. High pressure steam is injected to sustain the temperature during the reaction time. With the addition of air and adequate temperature and pressure, oxidation of the organic material takes place.

The oxidation results in the formation of the following by-product:

1. Carbon dioxide
2. Water vapour
3. Residual water (bound water extracted from the sludge)
4. Oxidized sludge

As the mixture is discharged from the Reactor, it surrenders its heat in Heat Exchangers to the fresh incoming sludge and air mixture.

Cooled, oxidized sludge is allowed to settle in Decant Tanks for approximately one hour. The settled sludge is pumped to Vacuum Filters where free water is removed from the oxidized solids without chemical conditioning. The resulting sterile filter cake is then removed for storage and ultimate disposal. The Decant Tank supernatant and the filtrate which contain about 2000 ppm suspended solids and 6500 ppm BOD should be held in available storage tanks and then returned to Aeration Tanks during periods of low flow. Figure 7-2 illustrates the Wet Air Oxidation Process.

DEWATERING

At present there are several methods available to de-water sludge. These methods include: (1) Drying Beds (2) Vacuum Filtration (3) Centrifuging (4) Sludge Lagoons and (5) Heat Drying.

It should be noted that in the first four methods above the sludge cake must be disposed of by incineration or land disposal, whereas that from the heat drying process can be used as a soil conditioner.

Drying Beds (Figure 7-3)

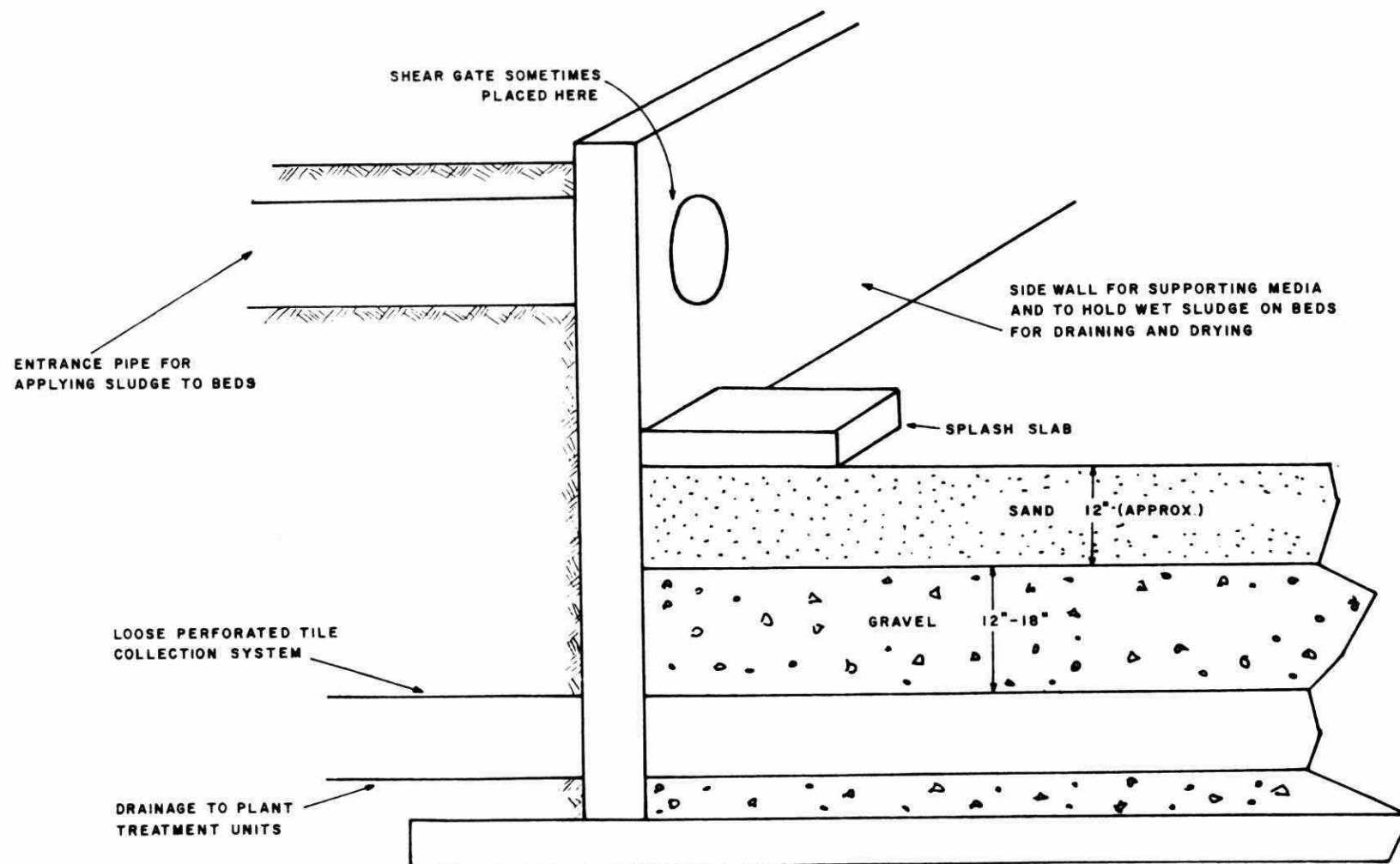
One of the more simple and economical methods of dewatering sludge is the use of drying beds. Although not used extensively in Ontario, approximately 2/3 of the sewage treatment plants in the United States have them. Using this method, a sludge can be dried to approximately 25 per cent (%) or more dry solids during a period of several days of dry weather. The de-watered cake is usually loaded onto a truck by using a shovel or garden fork. The reason heavier, mechanical equipment is not used is because the underdrain system cannot withstand heavy loads on it. The surface area required for sludge drying beds is determined first by climatic conditions.

The basic principle in dewatering of sludge on sand drying beds is filtration of the water through the sand and surface evaporation. The filtration usually takes place during the first few days, but depends on the sludge characteristics and depth of sludge applied to the drying bed.

After the filtration stage is completed the sludge then dries to an equilibrium moisture content with the surrounding air. Therefore the drying does not only depend on temperature but on the relative humidity of the air and the nature of the water in the sludge. It should be noted that some water in certain types of sludge are bound for example: raw and partially digested, and therefore does not dewater easily. However digested sludge is easily dewatered because it contains a low bound water content.

Figure 7-3

SLUDGE DRYING BED (SCHEMATIC)



Unless the sludge drying bed is properly constructed it is of little use. Sludge drying beds normally consist of approximately 12 inches of sand over approximately 18 inches of gravel. The bed is drained by the underdrains placed in gravel about 9 feet apart; this space will depend on sub-soil characteristics. The sub-natant from the underdrain system should be returned to the primary clarifier or aeration section of the treatment plant for further treatment. Sidewalls of the beds are made of concrete, wood or earth berms. The height of the sidewalls is usually 1 foot and the sludge is usually pumped to a level of 6 to 10 inches. It should be noted that several little beds are better from an operation point of view than one large single bed. The width of the bed is flexible; however, through practice it has been found that 20 feet is a good operational width. The length is usually less than 100 feet. Sludge may be expected to flow approximately 100 feet from a single outlet when the grade of the bed from the outlet is 5 feet per thousand feet.

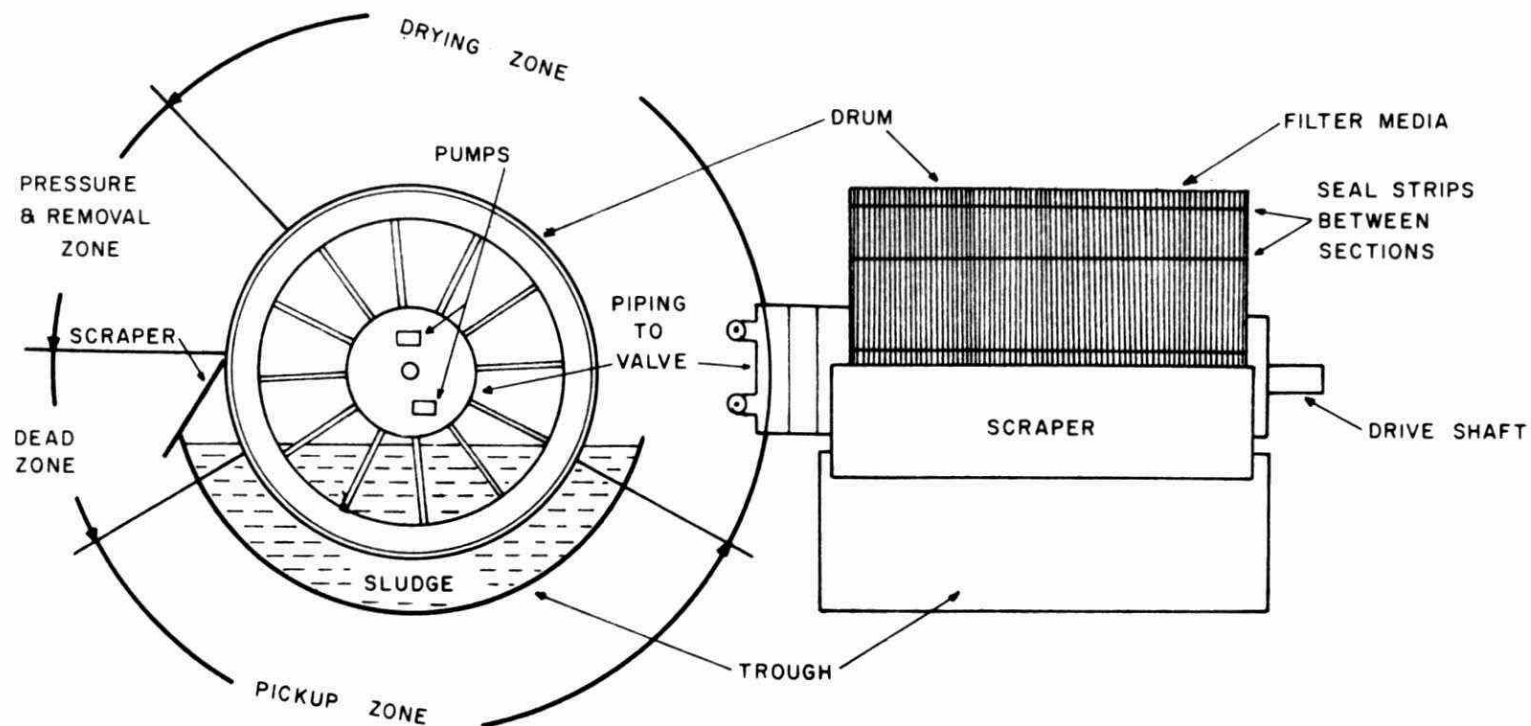
Although sludge drying beds are not extensively used, usually in Ontario the ones which have been designed and operated properly have given satisfactory results.

Vacuum Filtration (Figure 7-4)

Vacuum filtration is one of the most widely used types of mechanical sludge dewatering devices. Filters are adaptable to handling the various forms of raw and digested sludge. The basic process of filtration is separation of the solids from the liquid by means of a porous media which retains the solids (filter cake) and lets the liquid portion pass through (filtrate). The filter media used are of four basic types: (1) Fabric Covered Filter (cotton, wool, felt, dacron, saran, polyethylene and others), (2) String Filters (These filters use a fabric media but the sludge cake is removed from the drum by strings which pass around it), (3) Travelling Belt Filters (These consist of a stainless steel woven wire belt which serves as filter media),

Figure 7-4

SLUDGE VACUUM FILTER



(4) Coil-spring Filters (Two layers of coiled steel springs are placed in a corduroy fashion around the drum. As the layers leave the drum, they are separated from each other and the filter cake is lifted off and discharged).

The filtration process is accomplished by means of a horizontal drum covered with a filter media. The drum is rotated in a tank with about one quarter of the drum submerged in wet sludge. Valves and appurtenances are arranged in such a manner that as the drum rotates, a vacuum is applied on the inner side of the filter media, drawing out water from the sludge and picking up a layer of sludge on the filter media. The vacuum is continued as the drum revolves and this continuous vacuum pulls the unbound water from the sludge mat, leaving a semi-dry cake of sludge on the outer surface. The sludge cake is then scraped, blown or lifted away from the drum before it enters the sludge tank again.

The performance of the vacuum filter is measured by the rate at which dry solids are produced (pounds per hour of dry solids filtered per square foot of filter surface). These rates will vary according to the type of filter media used and type of sludge dewatered.

The filtering rates for various sludges are indicated below:

Table 7-2 Filtering Rates

Type of Sludge	Average Yield lb/sq ft/hr	Range
Primary	8	6.5-11.5
Primary digested	7	4.5-12.5
Primary digested-elutriated	7	3.2-13.0
Primary and Activated	4	
Primary digested and Activated	3	2.3-3.2
Primary digested and Activated elutriated	3.1	

Operating costs for vacuum filtration vary greatly from one installation to the next. However, when final disposal is incinerated, then the vacuum filter can be used on non-digested sludges thereby eliminating the necessity of a digester and reducing the overall capital and operating cost for the treatment plant.

Centrifuging

One of the more recently established methods of dewatering is centrifuging. There are several types of centrifuges available and all have their particular application.

A centrifuge is basically a clarifier with the sedimentation taking place under forces greater than gravity. The centrifugal force produced in the machine acts on a suspended particle in the sludge, causing it to settle through the liquid component. By either rotating the bowl at high speed or by the addition of chemicals the settling forces acting on the solid particles are increased greatly.

Several variables affect the theoretical clarifying capacity of centrifuges:

1. Particle size, shape and maximum settling rate of the smallest particle to be handled.
2. The time under which the centrifugal force is available for settling.
3. The liquid depth through which the solid particles must settle.

The foregoing gives the basic theory behind the operation of centrifuges. Although the number of installations in Canada is very limited, good operating data has been obtained.

The operation of a centrifuge at Simcoe, Ontario determined that a good centrate, one which has a suspended solids content of less than 200 mg/l, a disposal cake, some in the order of 16-25% plus or minus 5% could be obtained at an overall cost lower than the conventional methods of disposal. It also determined that manpower was not a factor.

Sludge Lagoons

Another method of dewatering sludge is sludge lagoons. This method if dewatering was widely used in Europe; however, because of the large land requirements it has fallen in to disuse. The basic principles on which a lagoon operates is evaporation and supernatant withdrawal. Without both of these principles in operation the usefulness of lagoons is seriously limited.

During the last few years sludge lagoons have been in operation at the Kitchener WPCP in Ontario. Approximately half of their sludge production is directed to 20 acres of lagoons. There are three lagoons located at the project and one lagoon is filled yearly. It has been found through practice that operating levels should not exceed three feet if the sludge is to be dewatered. Certain periods of the year find the supernatant on the surface and in turn the supernatant is pumped to the primary clarifier of the plant. During the year when the third lagoon is being filled the first lagoon is emptied by drag line and dumptruck. To date this method of dewatering is very economical. However, the long term effects of the surrounding area have to be studied further.

Heat Drying

This method of volume reduction can be employed for most types of sludges - primary, secondary, raw, or digested.

Sludge is dried:

1. to reduce the volume of sludge by lowering the moisture content from 75 per cent to 10 per cent.
2. to retain the fertilizing properties of the sludge.
3. to retain and improve its soil conditioning properties.
4. to destroy organisms capable of producing disease.
5. to reduce odours in the sludge.

Equipment includes:

1. Rotary Kiln Dryer - This is a cylinder set on an inclined plane with length eight to ten times its diameter. The cylinder revolves at a very slow speed (4 to 8 rpm). The sludge to be dried enters at the upper end and is carried to the discharge by gravity as the cylinder rotates. Heated gases (up to 371°C) are introduced to the cylinder and mixed with the relatively cold sludge. The exhaust gases from the dryer must be oxidized at a temperature of 649 to 760°C in order to reduce serious air pollution.
2. Flash Dryer - Consists of a cage-type mill where the sludge particles are dried almost instantly as they are removed and held in suspension in a stream of hot gases (204°C). The gas-borne sludge particles are blown to a separator where the dried sludge is trapped and removed from the moisture-laden gases.
3. Spray Dryer - Consists of a vertical tower down which a current of hot gases flow. Fine particles of wet sludge are sprayed into the tower and the water evaporates from the sludge particles and passes off with the gases into the atmosphere.

Dried sludge from the rotary kiln is granular and may contain larger clinker-like masses which require grinding. The waste resulting from the flash and spray dryers is a fluffy material suitable for fertilizer use.

FINAL DISPOSAL

Incineration

Incineration is a popular method of sludge disposal at very large sewage plants. It has the advantage of freedom from odours, independence of weather and in reduced volume and weight of the end-product to be disposed of. There is a minimum size of treatment plant below which incineration is not considered economical since the process requires the use of expensive equipment.

Incineration is achieved by flash type incinerators, which are similar to the flash type dryers but at a temperature of approximately 871°C , and multiple-hearth furnaces where the sludge is burned to an ash.

Land Disposal by Liquid Haulage

Many municipalities are using this method of sludge disposal. It is popular where residences are located close to the plant or space is limited for lagoons or sand beds. It is a simple and economic procedure if the distance to the dump site is not too great.

Both raw and digested sludges may be spread on land where adequate aging and cultivation is affected. Where an adequate ageing period is not allowed the land should not be used for crops which may be eaten raw. *At no time should either raw or digested sludge be spread on growing crops which may be consumed raw.* Unless sludges are effectively heat dried they should not be spread on active grazing land. Forage crops which have been treated with sludges not rendered innocuous by heat drying should be cured before use.

With the exception of the nitrogen and phosphorous content in undigested activated sludge, the fertilizer content in sludge is small. Therefore, the greatest percentage of sludge products are classified as soil *conditioners*, and not fertilizers. Nevertheless, this material whether termed as fertilizer or soil conditioner, can provide valuable humus and trace elements to the soil. The three main constituents required in commercial fertilizer are nitrogen, phosphorous and potassium. Nitrogen and phosphorous are available in good percentage in sewage sludge while potassium is generally available in amounts less than 1 per cent.

The type of sludge treatment as well as the nature of the raw sewage have a great bearing on the value of the resultant sludge as a soil conditioner. With respect to nitrogen content, undigested activated sludge is greatest, with digested activated sludge, raw primary sludge, and digested primary sludge following in that order.

When disposing of sludge, great care must be taken to ensure that nuisances are not created. Common sense rules must be followed to prevent obnoxious odour complaints. When a municipality receives numerous complaints regarding refuse and sludge disposal, very restrictive regulations may be enacted.

Only very isolated dumping areas should be used for raw sludge and the applied material must be plowed in very quickly. Winter weather will prevent odours but it may be difficult to work the sludge into the soil early in the spring and obnoxious odours might develop at that time. In general, raw sludge products must be handled very carefully. It might be advisable to dispose of raw sludge at a landfill project, where daily coverage can be provided.

Digested sludge is less odourous and therefore immediate coverage is not as important. Liquid sludge can be spread evenly and thinly. Where quick drying is possible, on sandy and elevated dry land, it may be disposed of close to homes. Nevertheless, great care must be taken that obnoxious odours do not carry to residences and, furthermore, only well digested liquid sludge can be considered in this category.

Digested sludge cake must be handled more carefully. It is difficult to spread thin and therefore wet lumps of material may emit some offensive odours. If possible this material should be worked into the soil soon after spreading.

Sludge Composting

The composting of sewage sludge and municipal garbage into humus valuable as a soil conditioner and nutrient for plants is the alternative to landfill or incineration. However, the method is based on the recycling of wastes back to the soil and is therefore strongly dependent on the demand for the compost product.

Composting may be defined as the biological decomposition of organic solid wastes to a relatively stable end product.

SUBJECT:

SEWAGE TREATMENT
OPERATION

TOPIC: 8

CHLORINATION

OBJECTIVES:

The trainee will be able to

1. Name the seven (7) physical properties of chlorine.
2. Explain the main purpose for chlorination of sewage treatment plant effluents.
3. Name and explain four other uses of chlorine in sewage treatment plant operation.
4. Define:
 - a) Chlorine Dosage
 - b) Chlorine Demand
 - c) Chlorine Residual

Explain how they relate to each other.
5. Calculate the dosages of chlorine required to obtain the chlorine residual in the plant effluent.
6. List three methods used to determine chlorine residual.

CHLORINATION OF SEWAGE

PURPOSE

Chlorination means application of *chlorine*. The principal purpose of chlorination is *disinfection* of plant effluent - killing bacteria and viruses harmful to man. In the killing of the bacteria and viruses the chlorine does not do it directly but mainly by the formation of hypochlorous acid (free residual chlorination) which is formed when chlorine gas and water are mixed in the chlorinator and injected into the chlorine contact chamber. Chlorine is also used for:

1. The control of odours
2. The reduction of BOD
3. Aiding the activated sludge process
4. Sludge thickening.

Chlorine may be applied as a gas, as a gas dissolved in water, or in the form of a hypochlorite obtained from salts such as sodium or calcium hypochlorite which, when dissolved in water, release chlorine. Chlorine gas costs much less, is not as bulky as the hypochlorite form, and is generally used in sewage treatment, unless a relatively small quantity of chlorine is required.

CHLORINE PROPERTIES

Chlorine is a *poisonous* greenish-yellow gas with a penetrating characteristic odour at normal temperature and pressure. It is $2\frac{1}{2}$ times as heavy as air, and one of liquid chlorine equals 450 volumes of chlorine gas. It can be compressed into a liquid which has a clear amber colour. At -34°C chlorine has zero (0) vapour pressure, and at room temperature of 20°C its vapour pressure is 82 pounds per square inch. Chlorine has a high co-efficient of expansion. For example a temperature rise of 10°C (say 7°C to 21°C)

will increase the liquid volume from 84% to 89% in the cylinder. Such an expansion could easily rupture a cylinder or the feed line full of liquid chlorine. This is the reason for the regulation that chlorine containers must not be filled to more than 85% of their volume, and also this has to be considered when:

1. feeding chlorine gas from a cylinder
2. dealing with a leaking cylinder

Note: (For detailed procedures outlining the handling of chlorine gas cylinders refer to the Ontario Ministry of the Environment "*Basic Gas Chlorination Workshop Manual*").

Chlorine by itself is non-flammable and non-explosive but it will support combustion.

Summary

Greenish-Yellow colour gas (poisonous)
2½ times heavier than air
Amber colour liquid (when compressed)
High rate of expansion
Moderately soluble in water
Non-flammable and non-explosive
Supports combustion at high temperature

Physiological Effects

Chlorine can be detected by smell, even in very small concentrations. *The least detectable amount of chlorine in the atmosphere is about 3.5 (mg/l) and when this occurs, the operator should be alerted to potential hazards, such as leaks, or faulty equipment.* At higher concentrations, chlorine will have physiological effects. The maximum amount that can be inhaled for one hour without serious effects is about four (4) mg/l. At fifteen (15) mg/l, chlorine will cause irritation of the throat; at thirty (30) mg/l, it will cause serious spells; and at forty (40) to sixty (60) mg/l, it is extremely dangerous for one half-hour exposure. A few breaths of air containing 1,000 mg/l would be lethal.

REACTION OF CHLORINE IN SEWAGE

To determine at what points as well as how much chlorine should be applied to the treatment process, the action of chlorine when added to sewage must be understood.

Chlorine is an extremely active chemical that will react with many compounds to produce many different products.

1. If chlorine is added, it will first react rapidly with reducing compounds such as hydrogen sulphide and ferrous iron. No disinfection results.
2. As more chlorine enters solution, it will react with all of the reducing compounds and organic matter present, forming chloro-organic compounds, which will have a slight disinfecting action.
3. Chlorine added in excess of that required by Steps 1 and 2 will react with ammonia and other nitrogenous compounds to produce *chloramines*.

The chlorine used by these organic and inorganic reducing substances (Steps 1 and 2) is known as the chlorine demand.

Disinfection results from that amount remaining after the chlorine demand has been satisfied. The quantity of chlorine in excess of the chlorine demand is defined as the chlorine residual.

For example: if the chlorine residual was measured to be 0.6 mg/l, then the chlorine demand could be estimated:

chlorine dosage	7.5 mg/l
chlorine residual	<u>-0.6 mg/l</u>
chlorine demand	6.9 mg/l

To disinfect the plant effluent, sufficient chlorine must be added to satisfy the chlorine demand and leave a *chlorine residual* that will destroy bacteria. Disinfection of sewage has arbitrarily been defined as the addition of sufficient chlorine so that a chlorine residual of 0.5 mg/l is available for at least a *contact time* of 15 minutes. This has been found to give adequate disinfection. *The Ministry of the Environment expects this to be maintained at all times.*

The quantity of both organic and inorganic substances in sewage varies from place to place and from time to time, so the amount of chlorine to be added will also vary.

Chlorine is a surface-active agent and there is a reasonable chance that bacteria hidden within solid particles will not be killed by chlorine. For this reason, chlorine is added for disinfection purposes at a point *after* solids removal. Because of possible hidden bacteria within particles, chlorination cannot properly disinfect raw sewage.

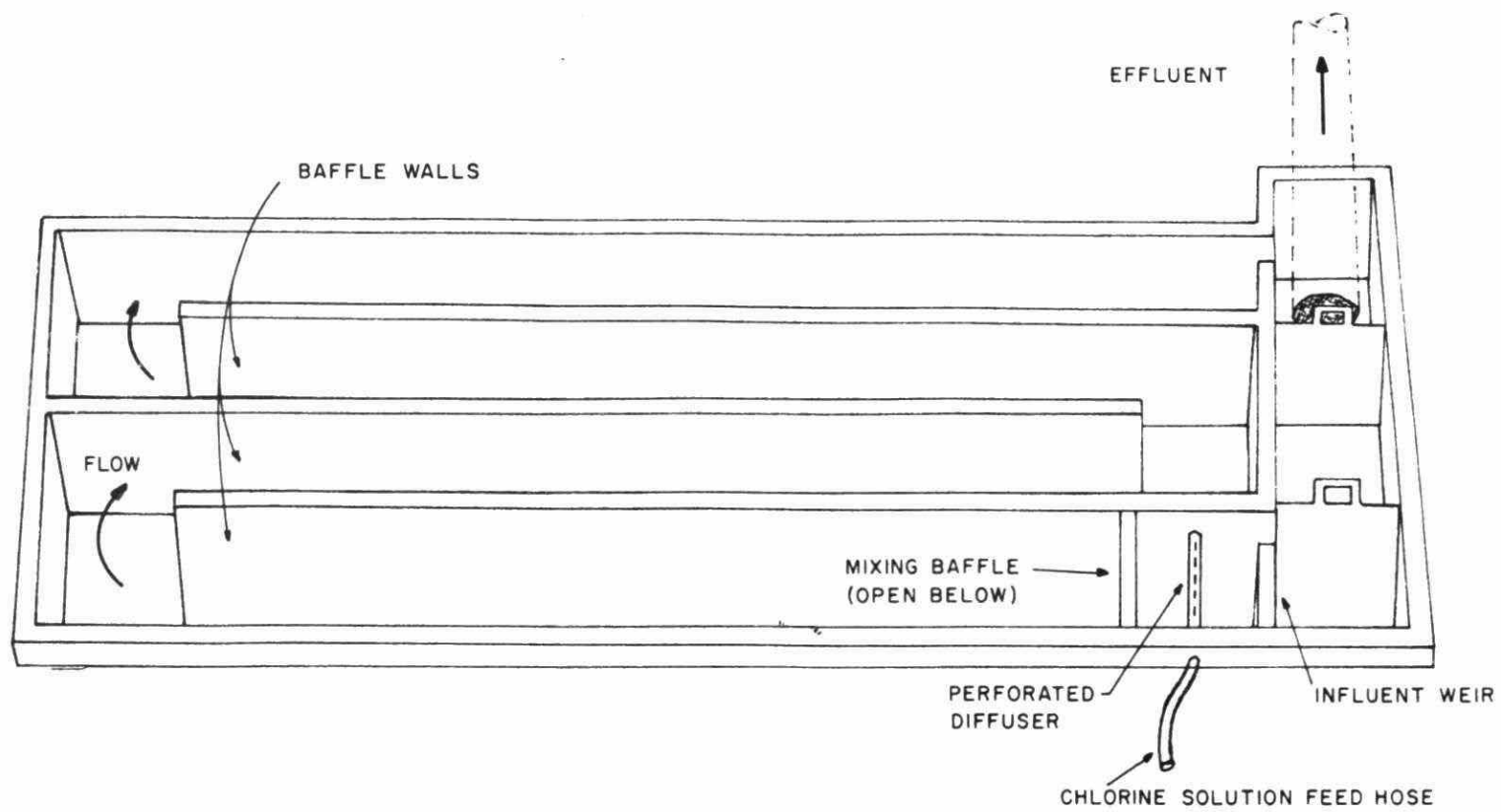
CONTROL OF CHLORINATION

As mentioned, a chlorine residual of 0.5 mg/l after 15 minutes of contact is required. To ensure at least 15 minutes of contact before discharging the effluent to a receiving stream a chlorine *contact chamber* (see Figure 8-1) is provided. The chamber is baffled to provide total mixing of chlorine with the effluent and prevent "short circuiting."

Accurate control of the chlorine residual may be impossible, due to the great variations in flow and strength of sewage. In small plants the residual should be checked each day when the maximum flow enters the plant. This normally ensures a sufficient chlorine dosage during the rest of the day. In larger plants the dosage should be adjusted during the night when the flow and chlorine demand is much lighter.

Figure 8-1

CHLORINE CONTACT BASIN



The operator should record all chlorine residual measurements and the amount of chlorine used each day. A comparison of the dosages and residuals can then be made. Also, there will be evidence that proper disinfection of the plant effluent is being performed continuously by the operating staff.

Chlorine Dosage

The dosage of chlorine or any chemical indicates the amount being applied. It is measured as a concentration, such as the weight of chlorine applied to a certain amount of water or sewage, usually in milligrams per litre (mg/l) or parts per million (ppm). Example: if a chlorinator is set to feed 45 lbs of chlorine per 24 hours and the sewage flow is at a rate of 0.60 MIGD, the chlorine dosage would be calculated as follows:

$$\begin{aligned}\frac{45 \text{ lbs}}{0.60 \text{ MIG}} &= \frac{75 \text{ lbs}}{1.0 \text{ MIG}} \\ &= \frac{75 \text{ lbs}}{1.0 \text{ MIG}} \times \frac{1 \text{ gal}}{10 \text{ lbs}} \\ &\quad (1 \text{ imp. gal. water} = 10 \text{ lbs.}) \\ &= 7.5 \text{ ppm} \\ \text{or} &= 7.5 \text{ mg/l}\end{aligned}$$

Therefore the chlorine dosage would be 7.5 mg/l with the feed rate and the flow in the example.

OTHER USES OF CHLORINE

While disinfection is the most important use, there are numerous other uses of chlorination at a sewage treatment plant. However, difficulty arises since most plants, unless they are very large, are not equipped to apply chlorine at the many different locations as may be required. One should be aware of the possible uses since most are effective in correcting problem situations.

Odour Control

Odours in sewage treatment plants that are due to an anaerobic condition will usually respond to chlorination. In most cases the problem is to find the best point of application for the chlorine. In the case of primary clarifiers where the sewage has become anaerobic during the sedimentation period, the chlorine should be added to the incoming sewage. When the odour develops in the sewers due to a low velocity, the chlorine should be added far enough up the sewer so that it has adequate time to control the anaerobic condition before the sewage leaves the sewer.

Industrial wastes with high oxygen demand such as come from packing houses, canneries, milk plants, etc., will turn anaerobic very rapidly and if this type of waste is found to be causing odours it should be chlorinated before it enters the sewer.

In controlling odours it is not necessary to chlorinate to a residual. It has been found that a dosage of 40-60 per cent of the chlorine demand will give satisfactory control.

Aid to Sedimentation

Chlorination of raw sewage will improve the rate of settling in primary clarifiers. This is especially true when the sewage is anaerobic as it destroys the gas forming organisms and prevents the sludge from rising.

BOD Removal

Chlorine reduces the BOD of sewage in two ways. Some of the decomposable matter is oxidized by the chlorine resulting in a permanent BOD removal. Other compounds combine with the chlorine to form chloro compounds, some of which are toxic to bacteria and others are no longer broken down by bacteria. The BOD reduction will vary from 15-35 per cent depending on the condition of the sewage. Generally speaking the lowest reduction is obtained in fresh sewage and the highest in anaerobic sewage. A BOD reduction of 2 ppm for 1 ppm of chlorine is obtained up to the point where a chlorine residual is obtained. Beyond this point the rate of oxidation drops off.

Grease Removal

Chlorination can be used ahead of a clarifier as an aid in grease removal. The chlorine will break the grease emulsions allowing the grease to collect in larger particles that are easier to remove by skimming.

Activated Sludge Process Control

There are a number of ways that chlorine can be used to advantage in operating an activated sludge plant. In some cases sludge bulking can be controlled by chlorinating the return sludge. This will require about 5 ppm of chlorine and should be continued until a satisfactory sludge index is obtained. Sometimes at the start of this treatment the effluent becomes quite turbid but this condition should clear within a day.

When waste sludge that is being returned to the primary clarifier tends to float, chlorination of this sludge will give better settling.

When an activated sludge plant is overloaded there are several points in the plant where chlorine can be added to reduce the load. It can be used ahead of the primary clarifier to reduce BOD and increase the amount of solids settled, or it can be added to the aeration channels to aid in oxidation. When added to the final clarifier, it can be used to control biological activity and prevent flotation of the sludge. The best point to add the chlorine can only be determined by experience and varies from plant to plant.

When a plant has become anaerobic from breakdown or overloading, chlorination is the quickest way to return it to an aerobic condition. In this case, chloride of lime is more effective than chlorine gas, as the pH is always low when a plant is anaerobic, and the lime raises the pH while the chlorine corrects the anaerobic condition. Care should be taken that the pH is not raised to the point where calcium carbonate is precipitated as it tends to form scale on the diffusers and plug them.

Supernatant liquor from digesters may cause a high oxygen demand on the activated sludge process that can be relieved by chlorination. Due to the high chlorine demand of this liquor, dosages as high as 80 ppm or more may be necessary to give adequate control.

Some success has also been attained in cleaning air diffusers by feeding chlorine gas into the diffuser headers.

Sludge Thickening

In some plants, sludges, both activated or primary, are thickened before they are pumped to the digester or dewatered. Chlorine can be used here to control bacterial action and better settling and concentration is obtained. To do this it is necessary to maintain a residual of 1 ppm of chlorine in the supernatant liquor above the sludge.

Breakdown of Concrete and Mortar

The hydrogen sulphide that develops in anaerobic sewage can cause other problems besides odour. This gas is quite soluble in water and will dissolve in moisture that has condensed on the walls and roof of a sewer. It is then oxidized by the air in the sewer to sulphuric acid and will dissolve the cement from the concrete and mortar and allow them to crumble. Chlorine, of course, is the answer to this problem, as it will oxidize the hydrogen sulphide before it condenses on the surface of the concrete and will also control the organisms that produce the gas.

TESTING FOR CHLORINE RESIDUAL

There are three methods used in testing for chlorine residual:

1. Orthotolidine Test
2. D.P.D. Test (Diethyl Phenylene Diamine)
3. Amperometric Titration Test

The detailed test procedures are described in Topic 13.

Orthotolidine Test

The OT method is an old one dating back to 1914, and is still in use in many plants. It is reasonably good for determining total chlorine residual but the Free chlorine residual result obtained by this method is only an approximate one.

D.P.D. Test

Research studies in chlorine chemistry have resulted in the development of a very simple procedure for the determination of residual chlorine compounds in water. Free or combined chlorine residual can be analyzed by this method. Differentiation and accurate determinations of these various forms of chlorine residual simplify the control of modern chlorination processes.

Amperometric Titration Test

The most accurate method of measuring free and combined chlorine residuals is by the oxidation-reduction titration procedure. This method requires the use of an electronic device called the Amperometric Titrator.

SUBJECT:

SEWAGE TREATMENT
PROCESS CONTROL

TOPIC: 9

SAMPLING AND RECORD
KEEPING

OBJECTIVES:

The trainee will be able to

1. Recall the purpose of sampling.
2. Define and recall the purpose of:
 - a) Grab sample
 - b) Composite sample
3. Recall the types of sampling devices.
4. Describe the two methods of collecting composite samples.
5. Recall the safety measures required to be taken when sampling.
6. Recall the location and type of samples to be taken in a plant.
7. Explain the importance of record keeping.
8. List and recall the purpose of six laboratory tests carried out to allow process control.

SAMPLING AND RECORD KEEPING

SAMPLING

PURPOSE

Sewage is treated to produce an effluent which will not impair the quality of the environment. If spending money is necessary to reduce pollution, then a knowledge of plant performance is necessary to justify the cost and to assess the treatment. *The purpose of routine sampling is to obtain data concerning the physical, chemical and biological characteristics of the waste stream regardless of the size or type of plant. This information can be used for control of the treatment processes, to show that regulations or standards have been observed, for estimating the effect of plant effluent on the receiving waters and for design of plant extensions.*

TYPES OF SAMPLES

Grab Sample

A *grab sample* can be defined as a single sample of wastewater taken without considering the time or the rate of flow. It is not very useful for calculating a waste loading since a single aliquot is not usually representative of average conditions. *Grab samples are only of value in determining the composition of either maximum or minimum flows.*

Composite Sample

A *composite sample* is defined as one which is built up, or composited from a series of grab samples taken at intervals during a fixed sampling period. It represents the average characteristics of the waste flow over the survey period and may be used to calculate waste loadings using the flow volume over the same period.

Composite samples are of the two types:

1. Those in which the grab samples are kept separate and analyzed separately to enable variations to be determined.

2. Those in which the grab samples are combined to form a bulk sample, all or part of which is subjected to analysis.

In the first type, a constant volume is taken at each interval regardless of the flow rate at that time. However, if a waste loading is to be calculated and it is known that the flow rate is not constant, the flow rate must be measured when each sample is taken.

In the second type of composite, where the aliquots are combined, a constant volume is taken at each interval only when the flow rate is constant. Where the flow rate varies, the amount of the aliquot taken at each interval must change in proportion to the flow rate *at the time when the sample is withdrawn from the waste stream*. For example, if at one sampling time the measured flow rate is 150,000 gpd and an aliquot of 500 ml is taken, at the next sampling only 250 ml should be taken if the measured flow rate is 75,000 gpd.

A constant time interval is usually chosen between aliquots of a composite sample, since most variations in waste characteristics occur on a time cycle. The time allowed between aliquots is determined by the variability of waste characteristics. If the characteristics vary rapidly, the aliquots must be taken frequently, say every half hour, while if the waste is of fairly uniform character, the intervals may be longer, say every hour. The most accurate average will, of course, be given by a continuously drawn sample, but unless automatic equipment is used, this will not be practical. Therefore, longer intervals, such as 10, 15, or 30 minutes are often used. However, aliquots should never be taken less than once per hour. A similar principle applies when characteristics vary with volume.

To give an accurate picture of the overall quality of raw sewage entering, of plant effluent leaving, and of the processes going on within the plant, a series of three 8-hour composite samples over a 24-hour period is the ideal, and is

strongly recommended. Daylight hour 8-hour composites are the next best choice, if sampling cannot be done regularly at night. In this case the occasional night composite should be attempted, even if this requires shortening a day shift to accommodate the extra hours worked.

TYPES OF SAMPLING DEVICES

There are two types of sampling devices, *automatic* and *manual*. Examples of each with their advantages and limitations are as follows:

1. Automatic

a) Vacuum Sampler

This apparatus consists of an evacuated sample container, an electrically (or mechanically) operated closing device and a length of tubing. The open end of the tube is placed in the waste stream and the timing mechanism is set to operate at the required intervals. When the closing device is opened, wastewater is drawn into the container.

Advantages of this apparatus include simplicity, reasonable cost and ability to function for long periods on a small storage battery. Its chief limitation is that it can only be used on a minimum lift.

b) Pump Sampler

This apparatus consists of a sample container, a pump, and interconnecting tubing. Many types of pumps may be used, among the most useful being chemical feed pumps, due to their ability to meter accurately small volumes of liquid. A timing mechanism may be incorporated.

Both vacuum and pump samplers may be equipped to sample in proportion to the flow rate.

In addition to the two types described above, there are many others based on similar principles and on various types of wheels, discs and rotating scoops.

2. Manual

Equipment used in manual sampling is simple and consists of bottles, lines, poles (able to be joined together), bucket or bottle holders, and weights.

COLLECTION OF SAMPLES

In keeping with the prime objective of a sampling programme (to obtain accurately representative samples), certain precautions must be taken to avoid errors. Whatever type of container is used, it must, of course, be "clean"; rinse with sample to be taken, or clean water.

NOTE: *When samples are taken through the plant, a good technique is to start with final effluent, primary effluent, raw sewage, activated sludge, and sludge return, raw sludge in digester samples. This sequence will prevent cross-contamination of samples. Where smaller samples are to be taken from a larger sample, care should be taken that the sample is representative (shake or stir sample well to ensure a thoroughly mixed smaller sample).*

SAFETY IN SAMPLING

No sample is worth obtaining at the risk of life and limb. Safety precautions should be observed at all times, including the following:

1. Never sample alone at night where lighting is poor.
2. Never enter a tank or other vessel or a sewer unless it cannot be avoided, and then *only when it is known that the atmosphere is free from noxious gases and there is no possibility of any material entering while sampling is in progress.*

Never do it alone and always use a lifeline.

3. Always remember that most organic liquids are highly inflammable and form explosive mixtures with air. *Smoke only in safe places and when sampling is completed.*
4. All chemical substances must be considered harmful (until proven otherwise) if ingested into the stomach or lungs, or by contact with the skin and eyes. It is vital to know what materials may be encountered during a survey and to use all necessary protective devices.

WHERE TO SAMPLE AND TYPE OF SAMPLE REQUIRED

REMEMBER: THE ANALYSIS IS ONLY AS GOOD AS THE SAMPLE TAKEN!

Taking good, representative samples of the wastewater entering and leaving the treatment plant is extremely important. The type of sample, where it is taken and how it is taken require conscientious care and attention since they will greatly influence the reliability of the data obtained.

The following points must be considered when taking a sample as well as where the sample is taken:

1. Raw Sewage, Primary Effluent, Plant Effluent

Composite samples should be taken wherever possible when sampling raw sewage, primary effluent, and/or plant effluent. A continuous 24-hour sampling period is desirable, and the sample taken should be proportional to the flow. An automatic sampler should be used.

Because of the variability in raw sewage, it is important that frequent aliquots be obtained of the raw sewage and primary effluent. The same frequency is not as important when sampling plant effluent.

2. Raw Sludge

The composition of raw sludge can vary widely between pumping cycles, even within a single pumping cycle. To get a representative picture of the sludge, use a sample composed of at least three equal-sized grab samples. Take one grab sample at the beginning of one pumping cycle, another grab sample near the middle of a second pumping cycle, and a third grab sample near the end of a third pumping cycle.

3. Anaerobic Digested Sludge - Primary Digestion

The primary anaerobic digester is usually heated and the contents well mixed and nearly homogeneous. A grab sample should be enough to determine the quality of the sludge, and the sample can be taken at some convenient location, *if it is representative*.

4. Anaerobic Digested Sludge - Secondary Digestion

A sample from the secondary digester can be taken when the sludge is removed from tank for disposal or haulage. If possible, a composite sample should be taken, made up of one grab sample at the beginning of the day's pumping, another in the middle, and the third sample taken near the end of the pumping.

5. Digester Supernatant

A sample is taken whenever the supernatant is withdrawn. A composite sample of at least three equal-sized aliquots should be taken: at the beginning, the middle and near the end of the recycle.

6. Aeration Tank (Mixed Liquor)

The aeration tank sample is taken at the effluent end of the aeration system. By necessity, it is a grab sample, taken at about the same time each day to ensure similar hydraulic conditions, (preferably mid-way through peak load conditions).

If there is more than one aeration tank, a sample should be taken from each tank.

For *return sludge*, a grab sample is enough to estimate the sludge solids concentration for wasting purposes.

7. Aerobic Digester

The contents are usually well mixed - a grab sample should do it.

LABORATORY TESTS

General

The processes within a plant, particularly biological processes, require constant and careful attention if they are to perform efficiently, and in some cases, if they are to perform at all. All the processes used in a sewage treatment plant (sedimentation, conversion of dissolved matter to particulate matter to gases and inert products) occur in nature. The difference is time; the plant does in hours what occurs in nature in the course of many days. Because these functions are made to perform more rapidly, some method of controlling processes to obtain maximum efficiency from the plant is necessary. There are many tests which can be done even in the larger plants, because a few simple tests are enough to control the process. Those normally done in the plant depend on the equipment available and the experience of the operating personnel. Regardless of the sophistication of equipment and personnel available, only those tests necessary and relevant to controlling and assessing the processes should be carried out.

Among the lab tests carried out are the following: Settleable Solids, Mixed Liquor Suspended Solids, Sludge Volume Index, Dry Solids, Total Solids, Volatile Solids, Dissolved Oxygen requirements, Volatile acids, Chlorine Residuals.

Settleable Solids (See Topic 11)

Settleable Solids are measured on mixed liquor samples. In this simple test, fresh mixed liquor taken at the end of the aeration tank is allowed to settle for 30 minutes in a 1-litre graduated cylinder. During the first five or ten minutes of the settling period the activated sludge should be watched for settling characteristics. A slow settling sludge will produce a clear effluent but may not allow enough time for separation in the clarifier. This can result in floc being carried over the weirs. Very fast settling sludge, on the other hand, tends to leave small particles in suspension, producing a cloudy effluent.

Mixed Liquor Suspended Solids

Mixed Liquor Suspended Solids determinations are used to control the quantity of activated sludge available to stabilize the organic matter in the incoming sewage. Analysis for suspended solids is normally done by filtering a convenient sample size (say 100 ml) on a dried, weighed filter paper (glass fiber filters are easy to use and pick up very little moisture from the air), drying the filter at 103°C and weighing it. Weighing of the filter need be to three decimal places, at most. Because it is a grab sample, results are recorded only to the nearest 100 mg/l. In controlling plant processes suspended solids are sufficient because it can be assumed that the volatile portion will remain a constant proportion of the total suspended solids. However, *volatile suspended solids* should be used for comparison between plants especially where one plant has phosphorus removal facilities. Volatile solids are determined on the sample previously dried for suspended solids. (Ignition of the filtered samples at 550°C will not cause any loss in weight of the glass fiber.)

At smaller plants a *centrifuge* is used to estimate mixed liquor suspended solids concentrations. The centrifuge reading (usually of a 15 ml sample) of the volume occupied by the solids is compared to a *calibration curve*. The calibration curve is prepared by plotting centrifuge readings

against suspended solids determined by weighing. Since this method assumes a constant density of the compacted sludge which is rarely achieved, even a recently prepared calibration curve may be in error by 30 per cent.

Sludge Volume Index

Sludge Volume Index (SVI) is defined as the volume in millilitres occupied by one gram of sludge, in one litre sample, after settling for thirty minutes. It is, therefore, calculated from the results of the 30-minute settling test and mixed liquor suspended solids determination. An average SVI is about 100 though it varies from plant to plant. The important thing to watch for is a change from the norm, because it signals a change in operation conditions and probably in effluent quality.

Total Solids and Volatile Solids Test

Total solids measure the combined amount of suspended and dissolved matter in a sample. The amount is determined by weighing the residue after completely evaporating the liquid portion of a measured sample. The total solids are comprised of volatile solids (mainly organic matter of animal or plant origin), and fixed solids (mainly inorganic compounds such as mineral salts, sand and silt). Volatile solids are those solids which are lost after ignition at 550°C.

Total solids are normally used as a measure of the concentration of sludges which are difficult to filter, since the dissolved solids form an insignificant fraction of the total solids present. This test is normally done on raw and digested sludges.

Dissolved Oxygen (See Topic 12)

Dissolved oxygen determinations are performed regularly on aeration tank contents to ensure that sufficient oxygen is being supplied to permit *aerobic* stabilization of organic matter. In the presence of oxygen, the organics are eventually broken down into carbon dioxide, water, nitrates, sulfates and inert minerals, none of which produces an odour.

In the absence of oxygen, the end products are carbon dioxide, methane, water, organic acids, alcohols, ammonia, hydrogen sulfide and a vile smelling dirty effluent. Both the Winkler method (including the HACH kit) and DO meters can provide accurate analysis for dissolved oxygen.

Volatile Acids

Volatile Acids analysis in *anaerobic* digesters can help to control the digestion process. Acid formation is an intermediate step in anaerobic stabilization. An accumulation of an excess amount of acids can inhibit the next stage in the breakdown of organic matter, which is the formation of lower hydrocarbons (mostly methane) and carbon dioxide. Some digesters operate normally at 100 mg/l volatile acids as acetic acid, others at 1000 mg/l. Volatile acids should be monitored regularly for *change* in acid level as an indication of impending change(s) in the process. Most digesters are well buffered against change in pH by the *alkalinity*, which is available largely in the form of ammonium bicarbonate to neutralize the acids formed, maintaining a constant pH in the range where methane-forming bacteria can thrive. It should be noted that all digester failures are not always due to, or signalled by, a rise in volatile acids content; heavy metal toxicity will produce digester failure with no change in volatile acids or pH.

Chlorine Residuals (See Topic 13)

Chlorine residuals are carried out on grab samples of plant effluent to ensure that adequate chlorine is being added to provide disinfection. While the treatment processes ahead of this stage remove a large portion of the organic matter, pathogenic (disease producing) bacteria and viruses will remain. In order to produce an effluent which is safe to re-use, disinfection using chlorine (or sodium hypochlorite) is employed. The method most commonly used to determine residual chlorine is a simple colour comparison method using orthotolidine. The development of the colour depends on time and temperature as well as the concentration of chlorine in solution.

Ministry Laboratory Tests

Other tests done by the Ministry laboratories and by larger plant laboratories are used to evaluate the performance of the plant and to estimate the effect of effluent discharge to the receiving stream. The most common analyses on plant influent and plant effluent are suspended solids, biochemical oxygen demand (BOD), total Kjeldahl nitrogen and total phosphorus.

Tests should be done for residual *total phosphorus* in the plant effluent where cost of phosphorus removal chemicals is high.

RECORDS

Obtaining analytical data is not an end in itself. The results of analyses, together with flow data, sludge volumes, gas production, etc., must be recorded in an understandable (and easy to use) form before the data can be used. Because a plant is not operated by reacting to the sewage coming in at this particular moment, but on the *expected* qualities and concentrations based on average values over the past few weeks or months, it is necessary to maintain comprehensive up-to-date records. In particular, the aeration mixed liquor concentration cannot be varied from day to day to maintain a constant F/M because BOD tests require five days of incubation. From the records, however, it is possible to establish a range of mixed liquor concentrations in which the plant will produce an acceptable effluent; the aeration tanks will then be operated in the middle of this range to allow for variations in wasting and in influent strength.

Systems for recording data can be simple or complex depending on the purpose of the record, the complexity of the operation and the judgement of the operator. In any case, the system adopted should be realistic and applicable to the particular facility. The most effective way to handle data, especially where a large number of plants are concerned,

is to record on preprinted forms. Samples of record sheets used by the Ministry of the Environment are shown in Figures 9-1, 9-2, 9-3. The first, *Plant Performance*, is common to all plants, describing influent and effluent concentrations and quantities, grit removal, phosphorus removal and chlorination. The second, *Aeration Performance*, deals with aeration tanks and aerobic digester or holding tanks where they apply. The third, *Sludge Digestion and Disposal*, records the parameters used in describing anaerobic digestion and ultimate disposal of the sludge. The three sheets are for a complete record for conventional activated sludge plants; the first two are for high rate, contact stabilization and extended aeration plants; and the first and third, for primary treatment plants with anaerobic digestion.

However up-to-date and comprehensive these records may be, they are of little value, particularly in planning plant expansion, if the figures do not accurately represent what is happening at the plant. Most of the data recorded is not entirely independent, so they can be checked against each other. All flow metering should be checked regularly and if a tank is emptied for repairs, the indicated total flow required to fill the tank should be checked against a calculated volume of the tank. Sludge volumes can usually be checked by drawdown of a sump. To determine if the sampling is representative, *mass balances* can be done on various units within a plant. In any unit in the plant, the total weight of solids going into a tank must equal the total weight out. (See Figure 9-4)

In a conventional activated sludge plant and in primary plants, all solids removal by the plant are ultimately removed from the waste stream by the primary clarifier; these include solids in the raw sewage, waste activated sludge, digester supernatant, etc. The remainder of the solids appear in the primary effluent.

Figure 9-1

WATER POLLUTION CONTROL PLANT

A - PLANT PERFORMANCE

PLANT 19... to 19...

PLANT FLOWS

MAXIMUM RATE - mgd
 MINIMUM RATE - mgd
 TOTAL DAILY FLOW - mil gal

MIN. FREQ	MON	TUE	WED	THU	FRI	SAT	SUN	TOTAL	AVG.

BYPASS - in million gallons (estimate where meter readings are not available)

PLANT
 PRIMARY CLARIFIERS
 AERATION SECTION
 CHLORINATION

d									
d									
d									
d									

PLANT INFLUENT

GRIT REMOVED - cu. ft
 BOD - mg/l
 SUSPENDED SOLIDS - mg/l
 TOTAL PHOSPHORUS - mg/l
 TEMPERATURE - °C

when removed									
1/w									
1/w									
2/w									
d									

PLANT EFFLUENT (including bypass)

BOD - mg/l
 SUSPENDED SOLIDS - mg/l
 TOTAL PHOSPHORUS - mg/l

1/w									
1/w									
2/w									

PHOSPHORUS REMOVAL CHEMICALS USED (record chemicals and quantity used)

d									
d									

CHLORINATION

Cl₂ to - lb
 Cl₂ to effluent - lb
 EFFLUENT Cl₂ RESIDUAL - mg/l

d									
d									
d									

NOTE: Plants without equipment to perform the analyses should submit samples at least twice a month to the nearest MINISTRY OF THE ENVIRONMENT laboratory. The analyses requested should be checked off on the day the samples were taken.

REMARKS

Figure 9-2

WATER POLLUTION CONTROL PLANT

B - AERATION PERFORMANCE

PLANT _____ 19__ to _____ 19__

MIN FREQ	MON	TUE	WED	THU	FRI	SAT	SUN	TOTAL	AVG
-------------	-----	-----	-----	-----	-----	-----	-----	-------	-----

AERATION INFLUENT (PRIMARY EFFLUENT)

TOTAL DAILY FLOW - mil gal
BOD - mg/l
SUSPENDED SOLIDS mg/l
TOTAL PHOSPHORUS mg/l

d									
l/w									
l/w									
l/w									

AERATION SECTION

NUMBER OF TANKS USED
30 min SETTLED SOLIDS ml/l
MLSS mg/l
MLVSS %
MOHLMAN SVI
AIR SUPPLIED - ml cu ft
AER² EFFLUENT TEMP °C
F/M lb BOD/day/lb MLSS
DISS. OXYGEN mg/l (max /min)

d									
d									
l/w									
d									
d									
l/w									
d	/	/	/	/	/	/	/		

RETURN and WASTE ACTIVATED SLUDGE

RETURN SL VOLUME mil gal
% of FLOW TO AERATION
SUSPENDED SOLIDS mg/l
VOLATILE SOLIDS % of SS
WASTE to _____ mil gal

d									
d									
l/w									
l/w									
d									

SECONDARY EFFLUENT (if different from plant effluent)

BOD mg/l
SUSPENDED SOLIDS mg/l
TOTAL PHOSPHORUS mg/l

l/w									
l/w									
l/w									

AEROBIC DIGESTER or SLUDGE THICKENING TANK

30 min SETTLED SOLIDS ml/l
SUSPENDED SOLIDS mg/l
VOLATILE SOLIDS % of SS
VOLUME REMOVED gal
SITE HAULED TO *

l/w									
When Removed									

NOTE * "SITE HAULED TO" - Use "L" for land application, "S" for sanitary landfill, "T" for transfer site (eg. storage lagoon), and "O" for others (specify). Designate each site by number (eg. L1, L2, S1, S2 etc) and keep a record of the locations.

REMARKS

Figure 9-3

WATER POLLUTION CONTROL PLANT

C - SLUDGE DIGESTION and DISPOSAL

PLANT _____ 19__ to _____ 19__

MIN FREQ	MON	TUE	WED	THU	FRI	SAT	SUN	TOTAL	AVG
-------------	-----	-----	-----	-----	-----	-----	-----	-------	-----

RAW SLUDGE

GALLONS TO DIGESTER

d									
d									
l/w									
l/w									

GALLONS TO

TOTAL SOLIDS %

VOLATILE SOLIDS % of TS

PRIMARY DIGESTER

TOTAL SOLIDS %

VOLATILE SOLIDS % of T.S.

ALKALINITY mg/l CaCO_3

VOLATILE ACIDS mg/l HOAc

TEMPERATURE deg C

l/w									
l/w									
l/w									
l/w									
d									

DIGESTED SLUDGE

GALLONS TO

GALLONS TO

TOTAL SOLIDS %

VOLATILE SOLIDS % of T.S.

WHEN REMOVED									

SUPERNATANT

GALLONS TO

SUSPENDED SOLIDS mg/l

WHEN REMOVED									

DIGESTER GAS

PRODUCED 1000 cu. ft.

WASTED 1000 cu. ft.

d									
d									

SLUDGE HAULAGE

LIQUID FROM cu.yd

- TOTAL SOLIDS %

- SITE HAULED TO *

DEWATERED FROM cu.yd.

- TOTAL SOLIDS %

- SITE HAULED TO *

WHEN HAULED									

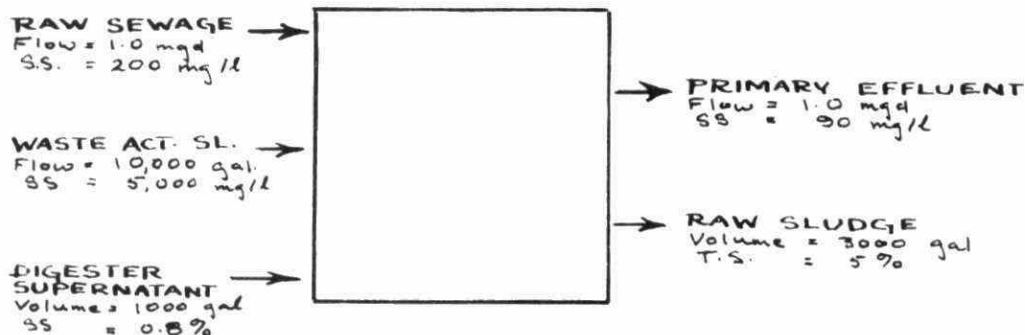
NOTE * "SITE HAULED TO": Use "L" for Land Application
 "S" for Sanitary Landfill Site
 "T" for Transfer Site (eg. storage lagoon)
 "O" for Others (specify)

Designate each site by number (eg. L1, L2, S1, S2, etc.) and keep a record of the locations of these sites.

REMARKS

Figure 9-4

SOLIDS BALANCE



$$\begin{aligned}
 \text{SOLIDS IN} &= 1.0 \times 10 \times 200 \text{ (raw sewage)} \\
 &+ 0.01 \times 10 \times 5000 \text{ (waste sl.)} \\
 &+ 1000 \times 10 \times \frac{0.8}{100} \text{ (supernatant)} \\
 &= 2580 \text{ lb}
 \end{aligned}$$

$$\begin{aligned}
 \text{SOLIDS OUT} &= 1.0 \times 10 \times 90 \text{ (pr. eff)} \\
 &+ 3000 \times 10 \times \frac{5}{100} \text{ (raw sl.)} \\
 &= 2400 \text{ lb.}
 \end{aligned}$$

SOLIDS IN should equal *SOLIDS OUT*. The above example agrees with 180 in 2500 (about 7%) and can be considered reasonable agreement. Assuming the metering is accurate, the major source of error is probably raw sludge sampling. It is not necessary to consider changes in volume due to waste activated sludge, digester supernatant or raw sludge pumping.

In activated sludge plants without primary clarifiers such as extended aeration plants, it is necessary to modify the relation somewhat. In this case, assuming 1 pound of BOD produces 0.7 pound of MLSS, the mass balance in the aeration tank becomes:

$$\begin{aligned}
 \text{lb Solids In} &= \text{lb BOD} \times 0.7 \\
 \text{lb Solids Out} &= \text{accumulation (or decrease) in MLSS (lb)} \\
 &+ \text{lb waste activated sludge} \\
 &+ \text{lb SS in effluent}
 \end{aligned}$$

The solids in the bottom of the clarifier can be ignored. However, in contact stabilization plants it is necessary to consider the solids in the reaeration tank.

Mass balances can be done on anaerobic digesters though a fairly long period of time should be used to establish average values. Again, solids in (in the form of raw sludge) equals solids out (as digested sludge and supernatant) and the solids lost to digestion.

Sampling points and/or methods should be altered, if necessary, to produce results which are consistent within the plant, that is, *for any unit within the plant, solids in plus accumulation must equal solids out plus destruction.*

CONCLUSIONS

Because plants are operated on the basis of what happened in the past, up-to-date records are necessary to operate a plant efficiently, following the trends in the changing sewage characteristics. In order to have reliable records, representative samples must be taken. Analysis of the samples will produce results by which the processes can be operated in the best range for that plant.

SUBJECT:

SEWAGE TREATMENT
OPERATION

TOPIC: 10

SAFETY

OBJECTIVES:

The trainee will be able to

1. Name three (personal) hazards common to treatment plants.
2. Recall the safety rules to follow when working in or around
 - a) Wet Wells
 - b) Chlorine Rooms
 - c) The Laboratory
 - d) Settling Tanks
 - e) Digesters
3. List at least eleven precautions to take for electrical maintenance.
4. Recall eight rules to follow to prevent body infection.
5. Recall ten general safety practices to be followed when working in the plant.

SAFETY PRACTICES IN TREATMENT PLANTS

INTRODUCTION

The dangers associated with plant operations emphasize the need for safety practices. Physical injuries and body infections are a continuous threat and occur with regularity. Explosions and asphyxiations from gases or oxygen deficiency occur. Although infrequent at any particular location, country-wide such accidents are a daily happening. These occupational hazards may be largely avoided by the execution of safe practices and the use of safety equipment. The dangers are many and carelessness all too frequently prevails until an accident results. Then it is too late.

It is the responsibility of supervisors to acquaint themselves with the hazards associated with plant maintenance and operation and to take steps to avoid them. Accident prevention is the result of thoughtfulness and the application of a few basic principles and knowledge of the hazards involved. It has been said that the "A,B,C," of accident prevention is "Always Be Careful". One must learn how to be careful and what to avoid. With this knowledge one can then always think and practise safety.

HAZARDS

The overall dangers of accidents are much the same whether in manholes, pumping stations or treatment plants. These result from:

1. Body infections
2. Physical injuries
3. Dangerous noxious gases or vapours, oxygen deficiencies and hazardous chemicals.

BODY INFECTION

Workers in treatment plants are exposed to the hazards of water-borne diseases, including Typhoid Fever, Amoebic Dysentery, Infectious Jaundice and other intestinal infections. Tetanus and skin infections must also be guarded against.

A majority of infections reach the body by way of the mouth, nose, eyes and ears. Therefore, washing your hands is a must before eating or smoking. Wear protection gloves where possible.

Soap preparations requiring no water rinse are available for field use. The common drinking cup should be banned, each man should have and use his own.

Typhoid and Tetanus inoculations are recommended. These may be obtained free of charge from local Health Officers.

This hazard to plant personnel although very real and ever present can be largely reduced by the operator himself by following a few basic rules of personal hygiene. A few of these self applied rules are as follows:

1. Never eat your lunch or put anything into your mouth without first washing your hands.
2. Refrain from smoking while working in open tanks, on pumps, or cleaning out grit channels, etc. Remember you inhale or ingest the filth that collects on the cigarette from dirty hands. Save your smoking time for lunch hours or at home.
3. A good policy is "never put your hands above your collar when working on plant equipment".
4. Rubber or rubberized cotton gloves, rubber boots and coveralls are designed for body protection against dampness and contact with dirt, wear them at all times when working in tanks, etc.

5. Rubberized or rain suits can be worn in very wet or dirty places and can be washed off with a hose and brush, the same as rubber boots.
6. Always wear your rubber boots when working in tanks, washing down etc., don't wear your street shoes.
7. Don't wear your rubber boots or coveralls in your car or at home.
8. Always wear rubber or plastic coated gloves when cleaning out pumps, handling hoses, etc.
9. Don't just wash your hands before going home, wash your face too, there is as much of your face to carry germs as there is of your hands.
10. Wear a hat when working around sludge tanks, cleaning out grit and other channels, don't go home with your head resembling a mop that just wiped up the floor around a cleaned out pump.
11. Keep your finger nails cut short and clean, they are excellent carrying places for dirt and germs.

PHYSICAL INJURIES - First Aid

Except for minor injuries, wounds should be treated by a doctor and reported for possible Workman's Compensation. Service truck and plants must have first aid kits. It is recommended that all plant personnel should receive "St. John Ambulance" first aid instruction.

It is a "Compensation Board" regulation that any plant having five (5) or more people working as a group on any shift, one of them is required to hold a "St. John Ambulance Certificate" in first aid. Remember, no cut or scratch is too minor to receive attention.

HAZARDOUS MATERIALS

The dangers of hazardous material are dealt with later in this topic.

THE PLANT SAFETY PROGRAM

Before starting a safety program, the full co-operation and active support of management is needed. One person in the utility organization must be responsible for the program. In a small water works system, that person may be the superintendent, while in a larger organization, another person who can devote part or full time to the job can be appointed.

The next step in setting up the program is to provide for:

1. Keeping injury records
2. Identification and location of the hazards
3. Making equipment, plant arrangements and working methods safe
4. Getting employees interested in safety
5. Controlling work habits

Injury Records

The keeping of injury records is basic to a safety program. With complete records, the program is given direction and is sure of success. The records should be kept brief but must contain all pertinent data. The forms should cover such items as:

1. Accident report
2. Description of accident
3. Physician's statement
4. Corrective action taken
5. Accident analysis chart

Locating the Hazards

The person responsible for the safety program should be constantly on the alert for hazards which may cause an injury to an employee. One of the best methods of attacking this problem is to search the records for the conditions and situations that have produced injuries. Records like this show the need for a corrective program.

Many other sources of information on hazardous conditions are available. These include safety manuals, insurance company brochures, etc. They should be used freely and frequently.

Equipment, Plant Arrangements, Working Methods

Nothing prevents an accident as effectively as the elimination of the cause. To preach safety while permitting unsafe conditions will discourage the cooperation required from employees. Only when safety is integrated with the job are workers convinced that the man responsible for safety wants to prevent accidents.

Some Protective Safety Equipment

The need for protective safety equipment in an accident prevention program has proven its value many times; the program cannot be successful if any phase of accident prevention is overlooked.

Use safety equipment as it was meant to be used. This should be compulsory during the performance of hazardous jobs.

Protect eyes and face when there is any possibility of injuries from hand tools, power tools, welding equipment, etc.

Protect feet with safety shoes to safeguard against injuries while breaking pavements, tamping trenches, handling materials, etc.

Protect head (with hard hats) to prevent serious injuries in construction, excavation or electrical work.

Protect hands (with gloves) to prevent injuries from occurring when handling materials, sharp objects, chemicals or electrical equipment.

Use air packs when hazards such as chlorine, painting or dusty areas exist.

Prevent accidents due to falls by using safety belts, scaffolds, etc.

GENERAL PLANT SAFETY

When working at the plant, observe the following common sense rules:

Keep walkways clear of loose objects such as pails, shovels, loose rope, etc.

Wipe up grease and oil *immediately*; salt or sand icy walks.

Pick up all tools, clean them and return them to their storage area.

When it is necessary to use tools in an empty tank or manhole, etc., lower them in a pail on a rope and remove them in the same way. Brooms and shovels can also be transported by rope. *Do not attempt to climb up and down ladders with your hands full of tools.*

Do not overload yourself when using stairways. Keep your load small enough to be able to see over it. Always keep one hand free to use the hand-rail.

Do not try to climb up or down a ladder or over a railing when handling a hose under pressure.

Always wear hip wader rubber boots with good treaded soles when washing down the floor of any tank. *Do not* wear rubber boots with worn soles and heels.

Always wear the rubber clothing provided when working in a narrow or confined passage where grit or sludge accumulates.

Always wear rubber or plastic coated, waterproof gloves when cleaning pumps, handling hoses, removing grit or sludge, etc.

When it is necessary to use an extension ladder to enter any empty tank, use the collector arms in the clarifiers to backstop the ladder legs. In an aeration tank, lash the ladder. Enter the tank from a walkway (not from a narrow dividing wall) and *always lash the ladder to a hand-rail.*

Always wear hard hats when working below ground level (in tanks, manholes, etc.) or under scaffolding.

Do not hang clothes on electrical disconnect handles, light switches or control panel knobs.

Replace all manhole covers and trap doors to wells. Close after using. If it is necessary to leave them open, *protect them with guard-rails.*

Use the proper tool when removing or replacing manhole covers. *Do not* attempt to move or close a manhold cover with your hands.

When working in manholes located in a street or road, post signs with blinking amber lights and red flags at each approach to the area.

Do not pull up grit-filled pails by rope when removing from tanks or wet wells. Use an "A" frame and pulley or some other type of support with a pulley. Be sure the support and pulley are fastened firmly to prevent them from toppling over during use.

Always wear a safety belt with a short rope and a safety snap when leaning out through the railings over any tank (or cleaning out spray nozzles, etc.)

Be very careful during repair work on fuel systems of gasoline engines. *Close the shutoff valve* from the tank and *be sure there is adequate ventilation* while draining the fuel system.

Check the ventilation of any enclosed or underground areas when gasoline operated pumps are to be used.

Do not refill a gas engine when in operation or while still hot. *Remove* spark plug from engine before cleaning out pump unit.

Building Maintenance

Periodic inspections are necessary to eliminate hazards (fire safeguards, etc.). Suggested repairs for safety should receive immediate attention. Floors, hallways, and stairways should always be well lighted, clean, orderly and free from oil, dirt and debris. Immediate repairs of hazardous electrical outlets and fixtures should be routine. Adequate sanitary facilities for employees must be provided. Hand-rails on steps and stairways should always be provided and used. *Good housekeeping must be maintained.*

Hand Tools

Hand tools are the cause of many accidents and injuries when improperly used and in unsafe condition. Therefore, use the right tool for the right job in the right way. Use protective safety equipment where there is a job hazard. Keep the work area clear of hazards, with plenty of working space for solid footing. Tools should be in good condition and used for the purpose for which they were intended.

Portable and Power Tools

All equipment should be grounded. Check wiring and equipment regularly for defects. Be very careful when using equipment in wet areas. Use protective safety equipment when operating grinders, buffers, or other tools when there is danger of flying material.

Tools and Machines

Use protective equipment when operating power equipment if there is any chance of flying objects or other injuries. Inspect all tools and equipment for safe operation. Necessary repairs or replacements should be made immediately. *Repair power tools and machinery only when the equipment is turned off.*

Welding

Use the proper protective equipment at all times. Check for fire hazards before cutting or welding in areas of inflammable or explosive mixtures. *Only authorized personnel should operate welding equipment. The Ministry of Labour requires a 2 3/4 lb fire extinguisher be fastened to the welding truck.*

Inspections of Tools and Equipment

Periodic inspections should be made of tools and equipment so that those that are broken or worn out may be replaced. *Report worn or broken equipment and be sure they are replaced or repaired as soon as possible.*

Ladders

Ladders should be inspected periodically and maintained in good order. *Use safety belts when awkward positions are necessary for the work. Do not use metal ladders for electrical work.*

Lifting

Always lift with the leg muscles instead of the back and be sure your footing is secure. Bend your knees and keep your back straight. Don't turn or twist your body when lifting. Get help if load is too heavy or awkward to handle. Use mechanical device for lifting wherever possible.

Sanitation

Washrooms, toilets, locker rooms, drinking fountains and showers that are clean, ventilated and adequately built are good for employee morale. Clean drinking water and paper cups should be available at each plant, especially if the employees are exposed to skin irritant materials.

Storerooms

Good housekeeping must be maintained at all times. Space should be well arranged to permit proper storage, handling and movement of materials. Inspections should be made regularly for fire hazards. Fire extinguishers should be in good order and easily accessible.

Working Area

A safe working area must be provided for efficient work. In the field, traffic should be controlled by the use of traffic cones, barricades, flags, etc., to protect the workmen as well as the public. In the material yard and storerooms, good housekeeping and properly planned storage and work areas must be provided for safe working practices. Shops, plants and offices should be planned for the most efficient production.

Trucks and Equipment

Routine inspections of trucks and equipment should be made. Any need for repairs should be reported and acted on as soon as possible. Only qualified and licensed operators should be permitted to use and operate vehicles and equipment. Never permit riders on trucks or other mobile equipment. Check electrical and any other hazards constantly when moving heavy equipment. All trucks should be equipped with first aid kits, fire extinguishers, and flares.

Barricades and Traffic Control

An adequate and safe work area must be protected. Sufficient traffic cones and barricades should always be carried by crews assigned to construction or maintenance work in streets. Paint barricades bright, visible colours and keep them in good condition. Be sure warning signs, flags, flares are adequate and in positions where they can be easily seen.

EQUIPMENT SERVICING

When servicing plant and equipment, Do Not:

1. Grease or oil or attempt to service any machinery while it is in operation. Pumps on automatic control must be locked out and key carried by the operator during servicing.
2. Make any adjustments to operating machinery while alone. If it is necessary to run the unit to adjust it, a second man must be present and be beside the stop and go switch.
3. Work around electrical panels, disconnects or switches alone.
4. Enter any crawl space under flooring for any purpose until the area has been ventilated. A second man should be present.
5. Service pumps and shafts in the dry wells of pumping stations, and in plants where the pumps and shafts are less than three feet apart, without shutting off all pumps and locking them out.
6. Under any circumstances, attempt to grease or service pump shafting while standing on beams, piping, loose planks, guard rails, or by leaning out, over or through guard rails. If a ladder must be used, then a second man must be present to hold the ladder steady and to provide any other assistance.

PRECAUTIONS FOR ELECTRICAL MAINTENANCE

1. Plan safety into each job. Orderliness and good housekeeping are essential for your safety and the safety of others.
2. Each employee shall be qualified both in experience and general knowledge to perform the particular electrical work which he is assigned. Outside contractor to be called in.
3. Study the job carefully to determine all of the hazards present and to see that all necessary safeguards and safety devices are provided for safe working conditions.
4. Examine all safety devices before they are used to ensure that they are in good condition.
5. In all cases where work is being performed on or close to live conductors or equipment, at least two men shall work together. When it is necessary for one to leave, the other workman shall not continue the work until the first man returns.
6. Consider the results of each action. There is no reason for you to take chances that will endanger yourself and others.
7. Satisfy yourself you are working under safe conditions. The care exercised by others can not be relied upon.
8. Wear close fitting clothing, keep sleeves rolled down, avoid wearing unnecessary articles while working on or close to live circuits or apparatus.
9. Use only approved types of rubber or leather gloves.
10. Protect yourself by placing an insulated medium between you and ground or grounded apparatus to keep any part of your body from providing a path for electrical current when working on conductors or apparatus that may be energized.

11. Use rubber mats when working on any electrical control panel or switch and disconnect boxes.
12. Open and close switches completely with a firm positive motion. Switches in a partly open position may arc or cause a flash-over with damaging results to the switch and possible injuries to the operator.
13. Open switches fully before removing fuses. To remove a fuse from a circuit carrying a current without opening the switch is particularly hazardous. Use an approved low-voltage fuse puller to remove fuses on a circuit of less than 500 volts (where no switch is provided) whether a disconnect is provided or not. Remove fuses by breaking contact with the hot side of the circuit first. Use the reverse procedure when replacing fuses. Insert the fuse in the cold terminal first.
14. Do not stand directly in front of panel to remove fuses or shut off disconnects.
15. Shut off the power when examining or making repairs or alterations on light and power circuits. When this is impractical Head Office must be contacted for further instructions before proceeding with the work.
16. Consider all electrical circuits to be dangerous. Treat dead circuits as though they were alive. This may prevent an accident as the circuit may be closed through an error of some other person.
17. Exercise extreme care when required to locate troubles on a series lamp circuit, before repairs are made make sure the power is cut off.
18. Lock or block open the control devices, open disconnect switches or remove fuses before examining, repairing or working on power circuits. After

these precautions have been taken, attach tie-up tags worded "WORKMEN ARE WORKING ON LINE." The tag shall bear the name of the workman. Tie-up tags shall remain on the opened devices until removed by the workman whose name appears on the tag. If the workman leaves without removing his tag, it may be removed only on authorization of Head Office.

19. Before working on line circuits at a point remote from the control switch, which has been tagged, it is recommended that the conductors be grounded at a point on the line between the switch and the work station.
20. Make a complete check of the circuit before applying power for the first time. This is to be done by a qualified man in charge of the repairs, all other workmen to stand off at a safe distance.

FIRE PROTECTION

Good housekeeping is the basis for fire prevention. Inspections should be made periodically and correction of fire hazards should be made as soon as possible. Consult local fire departments for recommendations.

Each operator should have first hand knowledge of fire extinguisher, its ABC rating point of contact and time of operation.

A CO₂ fire extinguisher can only be used in an open area where the chance of using up the local oxygen is minimal. Never grab the horn of the extinguisher to direct the CO₂. The gas being expelled will freeze your hand to the horn causing serious injury. There is a handle provided. Do not direct the CO₂ at anyone. To fight the fire you must approach the fire from upwind, pull the pin and aim directly on the burning area.

The approximate operating time for CO₂ fire extinguishers is as follows:

2½ lb.	10 sec.	± 2 sec.	2. BC.
5 lb.	14 sec.	± 2 sec.	4. BC.
10 lb.	14 sec.	± 3 sec.	6. BC.
15 lb.	25 sec.	± 4 sec.	8. BC.
20 lb.	30 sec.	± 4 sec.	8. BC.

Note: The 2. BC etc., refers to the type of fires and area the extinguisher covers. (BC) indicates electrical, gas, oil type fires, "A" type are wood, paper, etc., CO₂ will not be effective on "A" type fires.

(2) indicates the extinguisher will put out a fire of not more than 2 square feet in area.

Weight indicated refers to contents only.

A Dry Chemical extinguisher can be used in any area. Approach from upwind and pull the pin, you do not have to stand as close to the fire as with CO₂. Dry Chemical will put a blanket of chemical over the fire, smothering it.

Note:

1. All extinguishers must be refilled after using no matter what amount has been used.
2. All extinguishers must be hydrostatically tested every five years.

CHEMICAL HANDLING AND STORAGE

The Industrial Safety Act, Ministry of Labour, states that the employer is responsible for providing the necessary protective equipment and clothing for handling dangerous materials. It is the responsibility of the employee, both to his employer and to himself, to use and maintain them.

Eyewash fountains and deluge showers must be located within fifteen (15) feet of the entrance to any chemical handling area. Plenty of water should be available for washing up after handling chemicals. Protective clothing should be washed after use.

All areas where solvents or other compounds are used and stored must be well ventilated. The working area must be designed and constructed for the safety and convenience of the worker and for his efficient production. The ventilation should be by mechanical means *with the air intake drawing air from the outside*. In rooms where lime and other dry types of chemicals are used, install dust accumulators in the air discharge pipe.

Operate exhaust fans when handling any chemical whether liquid or dry.

Wear rubber boots, apron, gloves and eye shield or goggles when handling liquids. Wear nose and mouth filter masks and goggles when handling dry chemicals.

LABORATORY

1. A thorough knowledge of first aid for dealing with lab accidents is essential. Know the relevant sections of the antidote chart.
2. Wear protective clothing.
3. Practise good housekeeping. Keep all unnecessary equipment out of working areas. *Use a separate marked container for broken glass.*
4. Areas around sinks and taps should be kept clear so that chemicals spilled on one's hands or person can be washed off quickly.
5. Wipe up all spills immediately.
6. All reagent bottles must be clearly labelled so they can be identified. The date when the reagent was made up, or received, should be on the label since some chemicals, particularly nitrogen compounds, become unstable with age.

7. When diluting concentrated acids or bases, always add slowly to the water allowing time to cool. Use only heat resistant (Pyrex) glassware. When diluting sulphuric acid or when making up a solution of sodium hydroxide, cool the solution in a water bath.
8. Chromic acid cleaning solution is a mixture of sodium or potassium dichromate in concentrated sulphuric acid. It dehydrates and oxidizes most organic matter, including clothing.
TREAT IT WITH CARE!
9. Use water as a lubricant when making glass to hose connections. For vinyl tubing, hot water can be used to make the plastic more pliable. Gloves should be worn when making hose connections to glass tubing.
10. Suction bulbs should be used on all pipets. A valved type sold as a "PROPIPET" will save fumbling.
11. Combining chemicals found in the laboratory without knowing how they will react can produce unexpected and unpleasant results.
12. When disposing of any chemical in the sink, dilute with plenty of water.
13. Bottles of hazardous liquids should be stored near floor level in ventilated cupboards.
14. HASTE MAKES WASTE (and accidents). Planning can save far more time than hurrying (and produces fewer mistakes).

Characteristics of Dangerous Gases and Gas Fuels

Refer to Tables 10-1 and 10-2.

SAFETY PRACTICES IN WORK AREAS

The following paragraphs list some of the specific safety measures an operator should observe when carrying out his responsibilities in a plant.

No Smoking Areas

1. Influent buildings
2. Detritor rooms
3. Wet and dry wells of plant pumping stations
4. Pump rooms containing raw sludge pumps
5. Tunnels having pipe galleries carrying digester or natural gas pipe
6. Digester, digester buildings
7. Sewers, manholes
8. Sludge holding tanks (covered)
9. Near sludge thickening tanks while mixing with compressed air is underway
10. Sludge conditioning tanks in filter rooms
11. Sludge loading pipes to trucks
12. Sludge discharge pipes to drying beds

Hazardous Gases and Fuels

In handling chemicals in the sewage treatment process, the general safety requirements outlined earlier should be met. Operators should be aware of the hazards associated with chemicals used in a sludge treatment.

Sludge is treated with chemicals to improve its dewaterability. Many chemicals have been used for this treatment, such as sulfuric acid, alum, chlorinated copperas, and ferrous sulfate, but, because of its low cost, ferric chloride with or without lime has been the most commonly used.

Concentrated ferric chloride decomposes in the presence of light or moist air to yield hydrochloric acid and is therefore extremely corrosive. Consequently, all tanks, piping, and valves that handle FeCl_3 should be either rubber-lined or made of acid-resistant plastic. Ferric chloride storage facilities should be well vented. Employees handling this chemical should be equipped with acid-resistant goggles and rubber gloves, rubber suits, and rubber boots. At least one emergency eye bath and safety shower within a radius of 25 feet should be available for employees in areas where FeCl_3 is stored or used. In addition, the correct type of canister gas masks or self-contained air breathing equipment should be available in all areas where HCl gas could accumulate. Other chemicals used for sludge treatment require similar safety precautions.

Influent Building

1. Area must be tested for noxious gases or vapours and the percentage of oxygen before entry. It is essential these factors be known.
2. Safety goggles must be worn around Barminator, Comminutor and Mechanical Bar Screens.
3. Two men must be present when working in this area.

Grit Removal Area

1. Aerated Grit Chambers
 - a) Safety goggles must be worn because of the ever present splashing.
 - b) Rubber boots must be worn.
 - c) If a "Clam Bucket" with an overhead crane is used, care must be taken on entry to cab from the ladder.
 - d) Ground man must wear a hard hat and always be aware of the location of the Clam Bucket.

2. Detritor and Raker Arm

- a) Hands must be kept clear of the raker blades.
- b) Do not step over the raker arm.

Primary and Secondary Settling Tanks

- 1. During cleaning of launder area, two men must be present.
- 2. A safety harness and short safety line must be worn when cleaning launders.
- 3. Safety bars should be located across outfall pit of launders to prevent operator from stepping into it.
- 4. At no time should the operator climb out on the center ring of a round clarifier or step on the flytes of a rectangular clarifier without a safety harness and life line.

Pump Rooms

- 1. "Caution Pumps on Automatic" signs must be posted.
- 2. Vent fans must be on.

Aeration Tanks

These areas can become extremely slippery from the spray, great care in walking is required.

1. Diffused Air

- a) Ear Muff type noise protection must be worn when in the blower room. The noise level is usually over 90 db., which is in the hearing discomfort range.
- b) Metal catwalks must be secured and the ends not turned up.
- c) When cleaning spray defoamers a short life line and safety harness must be worn.

2. Mechanical Type

- a) Serious accidents have been caused by the wearing of *loose clothing* when working around motor drive shafts. Wear proper fitting clothing.
- b) Centre catwalks require safety railings on either side.
- c) Do not stand on aerator discs, as they may start up unexpectedly.

Digesters

- 1. Non-sparking shoes must be worn.
- 2. The vent fan must be turned on before entering control room.
- 3. Metal roofs require a non-slipping walkway to centre P.R.V. valve.
- 4. Do not weld in the area.

Chlorine Buildings

- 1. The following signs must be posted outside the room door:
 - a) Turn on Vent Fan
 - b) Danger Chlorine Storage
- 2. A "Fresh Air" air pack must be located within 15 feet of room door.
- 3. An eye wash bath must be located within 15 feet of room door.
- 4. Mechanical ventilation of the chlorine room shall be sufficient to produce 30 air changes an hour taking suction from within 18 inches of the floor.
- 5. Operator must wear safety goggles and a pair of rubberized gloves.
- 6. Two operators shall be present for cylinder changing.

7. Fresh strong ammonia must be used for leak detection.
8. The chlorine room must NOT be used as a plant storage area.

Wet Wells

A wet well is classified as a confined space under Sec. 84-88 of the Industrial Safety Act, 1975. Before entering the operator must:

1. Test for oxygen content using an oxygen meter. DO NOT ENTER unless the oxygen content in the atmosphere registers between 18% and 23%.
2. Test the noxious gases and vapours using a combustible gas analyzer.
3. Test for Hydrogen Sulphide using the colorimetric test. Tests for other gases may also be necessary.

The operator must also take the following precaution on entry:

1. If any atmospheric contamination is suspected, a fixed or portable vent fan of 700 cfm capacity must be used before and during entry. If no vent fan is available, a portable air pack must be worn.
2. Explosion and waterproof lighting must be used.
3. An operator with a man hoist must be located at all times at the entrance to the wet well to monitor the meters and observe the operator inside.
4. If a man hoist is not available two operators must be at the entrance.
5. A parachute type harness and lifeline and hard hat must be worn.
6. A step-through parting is required at the ladder entrance.

Dry Well

1. Vent fan shall be started before entering the pumping station and left operating continuously while the operator is in the station.
2. "DANGER PUMPS ON AUTOMATIC CONTROLLER" signs should be posted at the control panel floor level, and the pump floor level.
3. "NO SMOKING" signs should be posted at the pump floor level.
4. Lock out switches at control panel when working on any pump at any floor level.

Table 10-1

CHARACTERISTICS OF DANGEROUS GASES ENCOUNTERED IN SEWERS, SEWAGE PUMPING STATIONS AND SEWAGE TREAT PLANTS

GAS	CHEMICAL FORMULA	COMMON PROPERTIES*	SPECIFIC GRAVITY OR VAPOUR DENSITY (AIR=1)	PHYSIOLOGICAL EFFECT*	MAX SAFE 60-MIN EXPOSURE (% BY VOL. IN AIR)	MAX SAFE 8-HR EXPOSURE (% BY VOL. IN AIR)	EXPLOSIVE RANGE (% BY VOL. IN AIR) LOWER UPPER LIMIT LIMIT	LIKELY LOCATION OF HIGHEST CONCENTRATION	MOST COMMON SOURCES
CARBON DIOXIDE	CO_2	COLORLESS, ODORLESS WHEN BREATHED IN LARGE QUANTITIES MAY CAUSE ACID TASTE. NONFLAMMABLE. NOT GENERALLY PRESENT IN DANGEROUS AMOUNTS UNLESS O_2 DEFICIENCY	1.53	CANNOT BE ENDURED AT 10% MORE THAN FEW MIN, EVEN IF SUBJECT IS AT REST AND OXYGEN CONTENT NORMAL. ACTS ON RESPIRATORY NERVES.	4 TO 6	0.5	- -	AT BOTTOM; WHEN HEATED MAY STRATIFY AT POINTS ABOVE BOTTOM	PRODUCTS OF COMBUSTION, SEWER GAS, SLUDGE. ALSO ISSUES FROM CARBONACEOUS STRATA.
CARBON MONOXIDE	CO	COLORLESS, ODORLESS, TASTELESS, FLAMMABLE, POISONOUS.	0.97	COMBINES WITH HEMOGLOBIN OF BLOOD. UNCONSCIOUSNESS IN 30 MIN AT 0.2 TO 0.25%. FATAL IN 4 HR AT 0.1%. HEADACHE IN FEW HR AT 0.02%	0.04	0.01	12.5 70.0	NEAR TOP, ESPECIALLY IF PRESENT WITH ILLUMINATING GAS.	MANUFACTURED GAS, FLUE GAS, PRODUCTS OF COMBUSTION, MOTOR EXHAUST, FIRES OF ALMOST ANY KIND.
GASOLINE	C_5H_{12} TO C_9H_{20}	COLORLESS, ODOR NOTICEABLE AT 0.03% FLAMMABLE.	3.0 TO 4.0	ANESTHETIC EFFECTS WHEN INHALED. RAPIDLY FATAL AT 2.4%. DANGEROUS FOR SHORT EXPOSURE AT 1.1 TO 2.2%.	0.4 TO 0.7	0.10	1.3 6.0	AT BOTTOM	SERVICE STATIONS, GARAGES, STORAGE TANKS, AND HOUSES.
HYDROGEN	H_2	COLORLESS, ODORLESS, TASTELESS. FLAMMABLE.	0.07	ACTS MECHANICALLY TO DEPRIVE TISSUES OF OXYGEN. DOES NOT SUPPORT LIFE.	-	-	4.0 74.0	AT TOP.	MANUFACTURED GAS, SLUDGE DIGESTION TANK GAS, ELECTROLYSIS OF WATER. RARELY FROM ROCK STRATA.

* PERCENTAGES SHOWN REPRESENT VOLUME OF GAS IN AIR.

Table 10-1

CHARACTERISTICS OF DANGEROUS GASES (CONTINUED)

GAS	CHEMICAL FORMULA	COMMON PROPERTIES*	SPECIFIC GRAVITY OR VAPOUR DENSITY	PHYSIOLOGICAL EFFECT *	MAX SAFE 60-MIN EXPOSURE (% BY VOL. IN AIR)	MAX SAFE 8-HR EXPOSURE (% BY VOL. IN AIR)	EXPLOSIVE RANGE (% BY VOL. IN AIR) LOWER UPPER LIMIT	LIKELY LOCATION OF HIGHEST CONCENTRATION	MOST COMMON SOURCES
HYDROGEN SULFIDE	H_2S	ROTTEN EGG ODOR IN SMALL CONC. EXPOSURE FOR 2 TO 5 MIN AT 0.01% IMPAIRS SENSE OF SMELL. ODOR NOT EVIDENT AT HIGH CONC. COLORLESS. FLAMMABLE.	1.19	IMPAIRS SENSE OF SMELL RAPIDLY AS CONC. INCREASES. DEATH IN FEW MIN AT 0.2% EXPOSURE TO 0.07 TO 0.1% RAPIDLY CAUSES ACUTE POISONING. PARALYZES RESPIRATORY CENTER.	0.02	0.002	4.3 46.0	NEAR BOTTOM, BUT MAY BE ABOVE BOTTOM IF AIR IS HEATED & HIGHLY HUMID.	COAL GAS, PETROLEUM SEWER GAS. FUMES FROM BLASTING UNDER SOME CONDITIONS SLUDGE GAS.
METHANE	CH_4	COLORLESS, ODORLESS, TASTELESS. FLAMMABLE	0.55	ACTS MECHANICALLY TO DEPRIVE TISSUES OF OXYGEN. DOES NOT SUPPORT LIFE.	PROBABLY NO LIMIT PROVIDED OXYGEN PERCENTAGE IS SUFFICIENT FOR LIFE.		5.0 15.0	AT TOP, INCREASING TO CERTAIN DEPTH.	NATURAL GAS, SLUDGE GAS, MANUFACTURED GAS, SEWER GAS. STRATA OF SEDIMENTARY ORIGIN. IN SWAMPS OR MARSHES.
NITROGEN	N_2	COLORLESS, TASTELESS. NONFLAMMABLE. PRINCIPAL CONSTITUENT OF AIR (ABOUT 79%).	0.97	PHYSIOLOGICALLY INERT	-	-	- -	NEAR TOP, BUT MAY BE FOUND NEAR BOTTOM.	SEWER GAS, SLUDGE GAS. ALSO ISSUES FROM SOME ROCK STRATA.
OXYGEN (IN AIR)	O_2	COLORLESS, ODORLESS.	1.11	NORMAL AIR CONTAINS 20.9% OF O_2 . MAN CAN TOLERATE DOWN TO 12% MIN SAFE 8-HR EXPOSURE, 14 TO 14%. BELOW 10% DANGEROUS TO LIFE. BELOW 5 TO 7% PROBABLY FATAL.	-	-	- -	VARIABLE AT DIFFERENT LEVELS.	OXYGEN DEPLETION FROM POOR VENTILATION AND ABSORPTION, OR CHEMICAL CONSUMPTION OF OXYGEN.
SLUDGE GAS	-	MAY BE PRACTICALLY ODORLESS, COLORLESS.	VARIABLE	WILL NOT SUPPORT LIFE.	NO DATA. WOULD VARY WIDELY WITH COMPOSITION.		5.3 13.3	NEAR TOP OF STRUCTURE.	FROM DIGESTION OF SLUDGE.

* PERCENTAGES SHOWN REPRESENT VOLUME OF GAS IN AIR.

Table 10-2

CHARACTERISTICS OF GAS FUELS

GAS	CHEMICAL FORMULA	B. T. U. CALORIFIC VALUE	SPECIFIC GRAVITY OR VAPOUR DENSITY	EXPLOSIVE LIMITS IN AIR % BY VOLUME		THEORETICAL AIR REQUIRED FOR COMPLETE COMBUSTION	MINIMUM IGNITION TEMPERATURE ° FAHRENHEIT	MAXIMUM FLAME TEMPERATURE ° FAHRENHEIT	FLAME SPEED PER SEC.	AUTO IGNITION TEMPERATURE
				LOWER	UPPER					
METHANE	CH ₄	913.1	0.55	5	15	9.56 to 1	1170°	3484°	0.85	1000
NATURAL GAS		1027	0.6	4.9	15	10.00 to 1	1170°	3562°	0.99	1000
PROPANE	C ₃ H ₈	2385	1.52	2.10	10.10	23.9 to 1	898°	3573°	0.95	871

TAKEN FROM FACTORY MUTJAL'S HANDBOOK OF INDUSTRIAL LOSS PREVENTION.

CHAPTER 37

SUBJECT:

SEWAGE TREATMENT
PROCESS CONTROL

TOPIC: 11

SETTLING TEST

OBJECTIVES:

The trainee will be able to

1. Demonstrate the settling test.
2. Calculate SVI.

SETTLING TEST

GENERAL

The 30-minute settling test is conducted on mixed liquor to determine the ability of the solids to separate from the liquid in the final clarifier, since the quality of effluent is dependent upon the absence of solids flowing over the effluent weir. The results of the settling test are also used, together with the suspended solids test, to determine sludge volume index. The suspended solids test and settling test should be run on the sample of mixed liquor. This will allow calculation of the Sludge Volume Index (SVI) or the Sludge Density Index (SDI).

The per cent settling rate can be compared for the various days of the week and with other measurements - suspended solids, SVI and per cent sludge solids returned, to provide a record of plant performance and a basis for process control.

APPARATUS

1,000 ml graduated cylinder.

30-minute timer or watch.

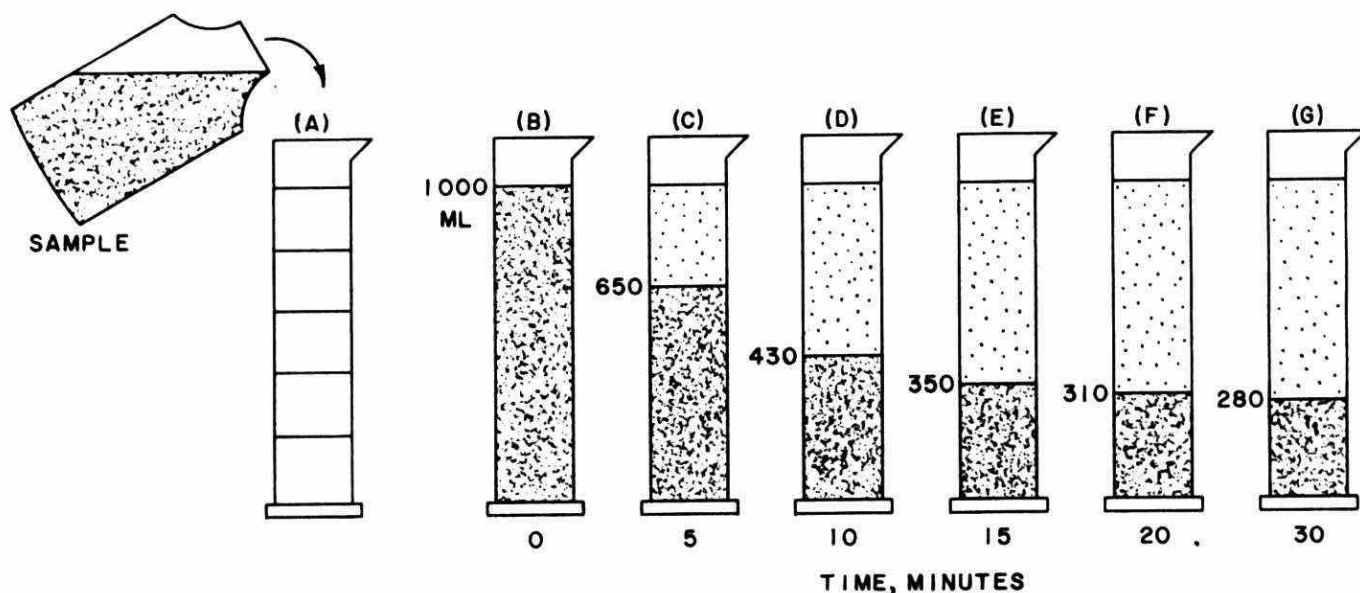


Figure 11-1 Settling of Activated Sludge Solids

PROCEDURE

1. Collect a sample of mixed liquor or return sludge.
2. Gently mix sample and pour into 1,000 ml graduated cylinder. (Vigorous shaking or mixing tends to break up floc and produces slower settling or poorer separation).
3. Record settling solids at 5-minute intervals on a line graph. See Appendix A.
4. Calculate % settleable solids - e.g. In Figure 11-1, % settleable solids after 15 minutes is

$$\frac{350}{1,000} \times 100 = 35\%$$

5. Plot % settleable solids on graph. See Figure 11-2.

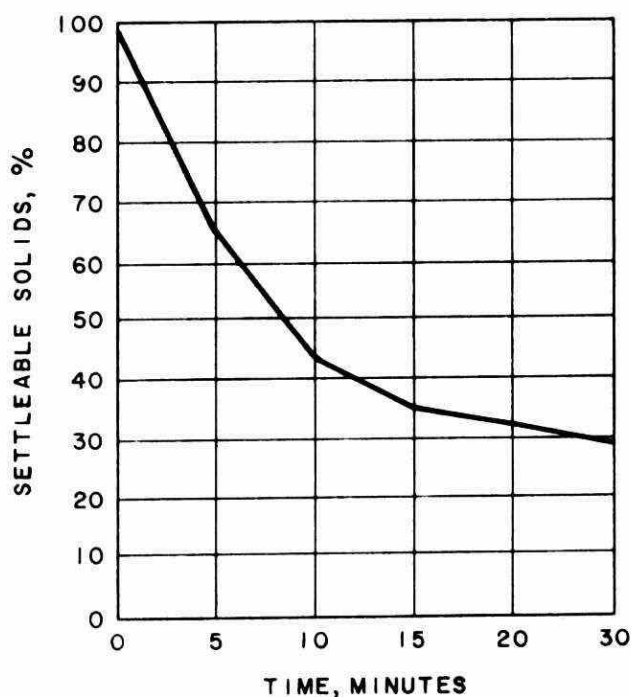


Figure 11-2 Graph Showing Settling of Activated Sludge Solids.

Note: If a cold sample of mixed liquor containing a high DO level (typically a winter condition) is allowed to warm up significantly during this test, the sludge may rise due to the desolubilization of gases. The test must then be repeated in a location where the sample will not warm up significantly.

SLUDGE VOLUME INDEX (SVI)

The Sludge Volume Index (SVI) is used to indicate the condition of sludge (aeration solids or suspended solids) for settling in a secondary or final clarifier. The SVI is the *volume* in ml occupied by one gram of mixed liquor suspended solids after 30 minutes of settling. It is a useful test to indicate changes in sludge characteristics. The proper SVI range for a plant is determined at the time when the final effluent is in the *best* condition regarding solids and BOD removals and clarity.

Example

Using a 1,000 ml cylinder, after 30 minutes settled solids = 180 ml or 18%.

Mixed liquor suspended solids = 1,500 mg/l.

Calculations

$$\begin{aligned}\text{Sludge Volume Index (SVI)} &= \frac{\% \text{ Settleable Solids} \times 10,000}{\text{Mixed Liquor Suspended Solids, mg/l}} \\ &= \frac{18 \times 10,000}{1,500} \\ &= \frac{1,800}{15} \\ &= 120\end{aligned}$$

SLUDGE DENSITY INDEX (SDI)

The Sludge Density Index (SDI) is used in a way similar to the SVI to indicate the settleability of a sludge in a secondary clarifier or effluent. The calculation of the SDI requires the same information as the SVI test.

$$\text{SDI} = 100/\text{SVI}$$

SUBJECT:

PROCESS CONTROL

TOPIC: 12

DISSOLVED OXYGEN
ANALYSIS

OBJECTIVES:

The operator will be able to:

1. Demonstrate the method of DO analysis using a DO meter.
2. Calibrate a DO Meter.

DO ANALYSIS

METHODS OF ANALYSIS

The dissolved oxygen level of a sample or contents of a basin or tank can be determined by a membrane type DO meter or the chemical, modified WINKLER METHOD.

DO METERS

General

Measurement of the dissolved oxygen (DO) concentration using a DO Meter, which are now common in many plants, is a good substitute for the Sodium Azide Modification of the Winkler Method. *Use of a DO Meter offers the following advantages:*

1. DO Meters are fast and accurate.
2. Results on DO Meters are unaffected by the floc present in the water.
3. Some DO Meters give direct readings in milligrams per litre (mg/l) or parts per million (ppm) while others give direct readings in per cent saturation. Simply take the meter to the site, put the probe into the liquid to be measured, turn on the meter, allow the meter to stabilize about 1 minute, and read the scale.
4. A direct reading of the liquid temperature is possible when using some DO meters.

The disadvantages are:

1. Some gaseous reactive compounds, such as sulphides, can interfere by fouling the probe.
2. The membrane area must be cleaned after each use by rinsing with water.
3. The batteries must be kept charged for use of the meter at any time.
4. Recognition of probe failure may be difficult when caused by poisoning or puncture.

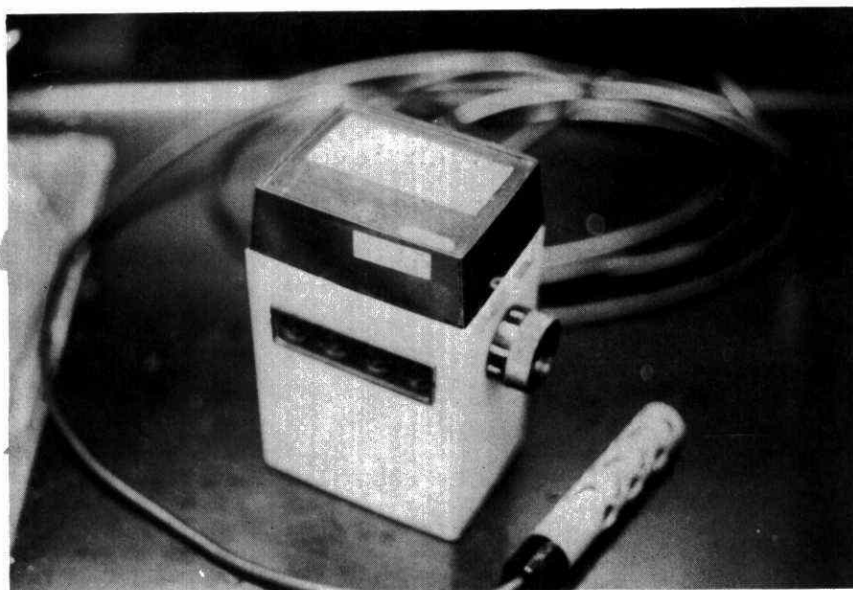


Figure 12-1 E.I.L. DO Meter & Probe
(Readout in per cent saturation)

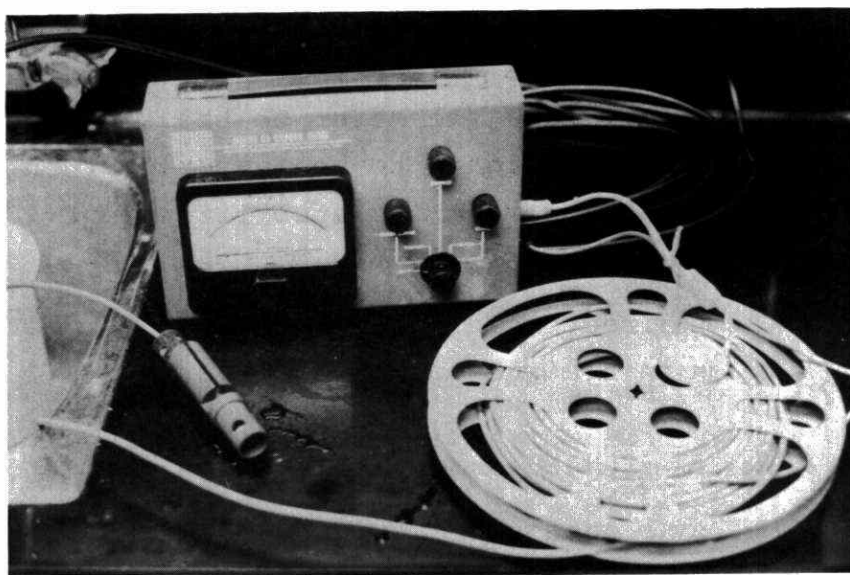


Figure 12-2 Y.S.I. DO Meter & Probe
(Readout in mg. per litre)

Calibration of the DO Meter and Probe

Calibration should be carried out regularly if the DO Meter is to be maintained according to the Manufacturer's Maintenance Manual accompanying the meter. *Calibration should be done at least every 2 weeks.*

ZERO CHECKING THE DO PROBE

It is advisable to check the response of the probe in a solution that contains zero DO. All membrane type DO probes become sluggish in response at DO levels of less than about 1 mg/l or 10% O₂ saturation. Some probes develop a "memory" of some low level of DO and will not readily read values less than this "memory" which can be as high as 1 mg/l.

To carry out a zero check, proceed as follows:

1. Prepare a zero DO standard solution by making up a 5% solution of sodium sulphite (Na₂SO₃) and adding a small crystal of cobalt chloride (CoCl₂).
2. Immerse the probe into this solution, turn the meter to read D.O., and watch the response of the meter movement. USUALLY the reading rises briefly, then drops sharply, slowing down as the needle approaches zero.
3. When the needle has stopped moving, or after 3 to 5 minutes, expose the probe to a high level of DO (e.g. air or aerated water).
4. Again, immerse the probe into the sodium sulphite solution and observe the meter response.
5. This cycling of the probe from zero DO to high DO should be repeated until the meter will easily read zero in the sodium sulphite solution.

Zero readings may not always be attainable especially with older DO sensors. Readings of 0.1 to 0.2 mg/l are acceptable in that case. Probes that do not approach a zero reading after repeated cyclings may require storing in the sodium sulphite solution overnight.

The "zero" adjust position on most DO meters is designed to electronically adjust the circuit to a simulated zero DO meter reading ...

Do not use this adjustment to set the meter reading to zero when the probe is immersed in sodium sulphite solution and the meter switch set to the "read" position.

CALIBRATION - LABORATORY PROCEDURE

After the zero check has been carried out, calibration of the meter is carried out as follows:

1. Take a sample (preferably tap water) which does not contain substances that interfere with either the probe reading or the modified Winkler Method.
2. Divide the sample into two even portions (A&B).
3. Using modified Winkler Method, measure the DO in portion (A) of the sample.
4. Using the DO Meter and probe, measure the DO in portion (B) of the sample.
5. Compare the DO values obtained in (3) and (4).
6. If the results coincide, the DO meter is calibrated.
7. If the results do not coincide, adjust the meter according to Manufacturer's specifications until it agrees with the modified Winkler Method.

Alternative Procedure for Calibration

A convenient and sufficiently accurate alternative method of calibrating the DO meter and probe is outlined for those not having access to the apparatus required to perform Winkler DO determinations.

It is sometimes difficult to perform steps (3) and (4) of the above method without altering the dissolved oxygen content by accidental aeration of one of the portions. Thus, the following alternative method of calibration may be used:

1. Take approximately 750 ml of distilled water, demineralized water, or tap water that is not excessively high in dissolved solids. Transfer this water to a clean 1 litre stoppered Erlenmeyer flask, or clean stoppered tall cylinder. The water should be at approximately room temperature.
2. Shake this water vigorously for 2 minutes to entrain as much air as possible and cause the sample to become saturated with oxygen.
3. Once saturated, this sample will keep its oxygen saturation level for some period of time unless it becomes contaminated or its temperature is allowed to change drastically.
4. Following is a list* of dissolved oxygen concentrations in mg/l attainable by air saturating a sample of water at various temperatures:

$^{\circ}\text{C}$	$^{\circ}\text{F}$	AIR SATURATED WATER DO mg/l
17	62.6	9.7
18	64.4	9.5
19	66.2	9.4
20	68.0	9.2
21	69.8	9.0
22	71.6	8.8
23	73.4	8.7
24	75.2	8.5
25	77.0	8.4
26	78.8	8.2
27	80.6	8.1

*Standard Method, 13th ed., page 480-1.

5. Immerse the DO probe which has been rinsed with tap water into the vessel containing the air saturated water, making sure that all the membrane surface and temperature sensing elements are also immersed.

6. If the probe is not fitted with a means of mechanical agitation, provide the necessary agitation by raising and lowering the probe about one inch two to three times per second, without exposing the membrane surface to the air.

Note: The probe will not respond properly unless the sample is moving past the membrane at about 0.5 ft/sec or faster. This velocity is provided by the above means of agitation.

7. Measure the temperature of the water used for calibration and set the temperature compensator dial on the meter to the measured value. Many meters have automatic temperature compensators, which eliminate the need for this adjustment.
8. Select the proper air saturation value from the above table and while agitating the probe adjust the calibration control on the meter to the selected proper DO value.

Note: If the meter scale is calibrated in percent oxygen saturation, rather than mg/l or ppm DO, set the meter to 100% on the scale.

9. The meter is now calibrated and ready for use. When taking measurements on a sample stream, be certain to provide the necessary velocity of sample past the probe. For example, aeration sections normally provide sufficient sample velocity, whereas final clarifiers would not.

Note: When not in use, always keep the membrane in the tip of the probe from drying by inserting in a flask of water.

WHY? If allowed to dry out, the probe can lose its accuracy until it is re-conditioned.

CHEMICAL METHODS

DO Sample Preservation of Mixed Liquor Samples

The DO present in the aeration tank (mixed liquor) is being depleted by the continuous activity of the micro-organisms. To prevent this and to ensure that a correct reading is obtained, 10 ml of copper sulphate-sulphamic acid reagent for each litre of sample should be added (as a preservative) to the sample container before taking the sample. This chemical preservative will kill the micro-organisms. The copper sulphate reacts with the alkalinity in the sample, forming a copper hydroxide floc which, as it settles, helps to remove the particles of sludge in the sample. The sulphamic acid, besides killing the bacteria, acts to prevent nitrite oxidation.

To obtain and preserve a sample for DO analysis by the Winkler or Hach Method:

1. Add 10 ml of copper sulphate-sulphamic acid reagent for each litre of sample to be collected in the sampling bottle.
2. Use a *tall* bottle having a capacity of about 1 quart. An assembly such as the one shown in Figure 12-3 can be used to fill the bottle, ensuring minimum liquid-air contact.
3. Lower the sampling device into the aeration tank in such a way that it will fill without entraining air.
4. Stopper the bottle and mix well by turning it upside down 4 or 5 times.
5. Allow the solids to settle until there is 50% or more clean liquor above the sludge.
6. Siphon the clear liquor into a BOD bottle. Keep the end of the siphon tube at the bottom of the receiving bottle to avoid aerating the sample, and fill until the liquor overflows the bottle. Stopper the bottle.

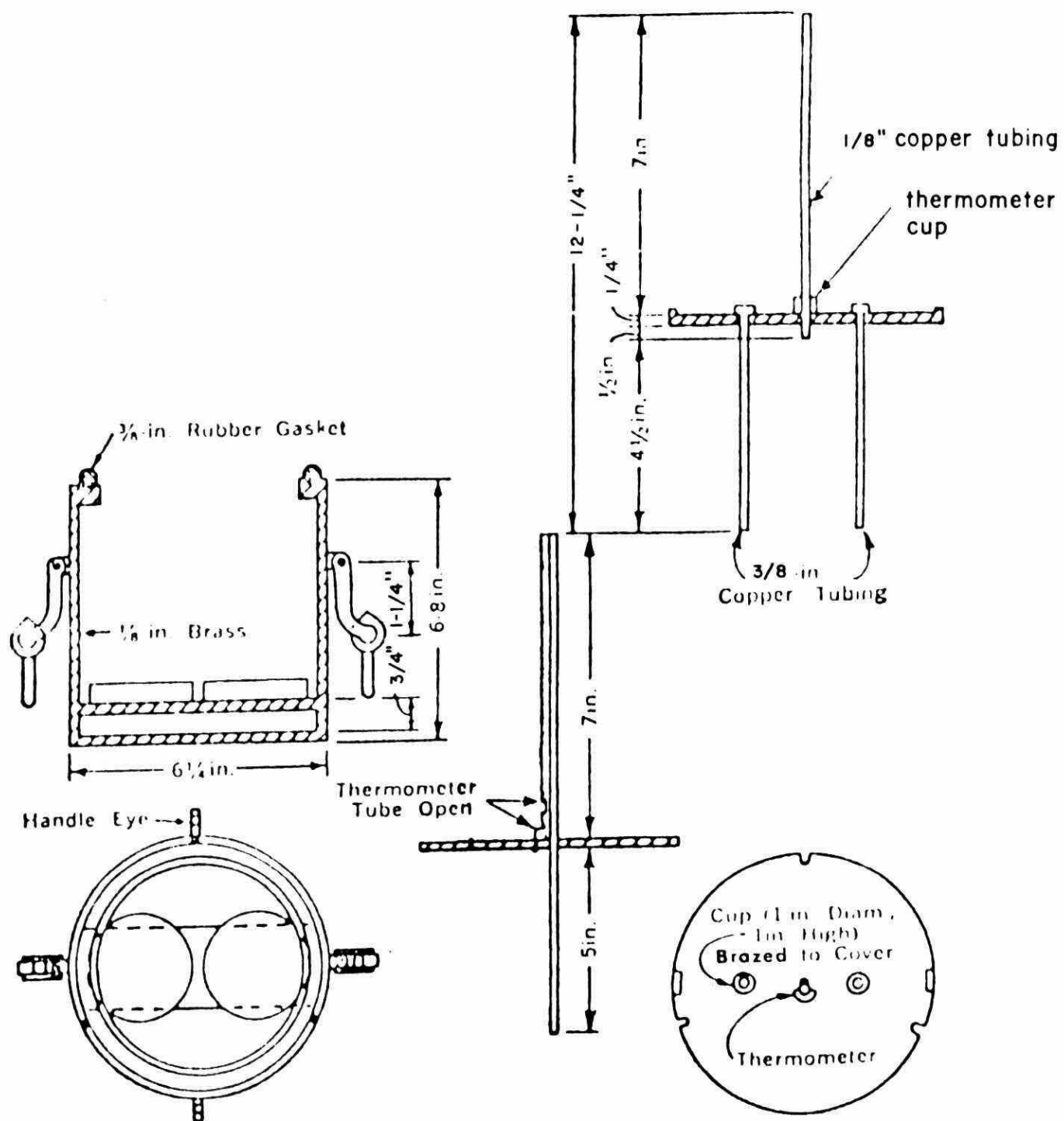


FIGURE 12-3 DO AND BOD SAMPLER ASSEMBLY

DO NOT CREATE TURBULENCE WHEN TRANSFERRING LIQUOR INTO THE BOD BOTTLE. THIS LEADS TO AIR ENTRAINMENT.

WINKLER METHOD

The principle of the Winkler Method is that it releases iodine chemically in proportion to the amount of dissolved oxygen originally present in the sample. Using a standard solution of sodium thiosulphate as a titrant, the amount of iodine and consequently the amount of oxygen present can be determined. It should be noted that the only solution which must be accurately made up (or standardized) is the sodium thiosulphate solution. Preparation of reagents is outlined further on in this topic.

Apparatus Required

1. Buret, capacity 10, 25 or 50 ml, preferably with a Teflon stopcock.
2. Buret support and stand.
3. BOD bottles.
4. Erlenmeyer Flask (200 or 250 ml capacity).
5. Three 10 ml pipets (Serological Pipets) or three 2 ml automatic pipets.
6. One 100 ml graduated cylinder.

Procedure

1. Remove the stopper, and add 2 ml of manganous sulphate solution with the tip of the pipet *slightly below* the surface of the liquid.
2. Using a fresh pipet, add 2 ml of alkaline iodide azide solution, with the tip of the pipet *slightly below* the surface of the liquid.

NOTE: SAFETY PRECAUTIONS

(i) When transferring solutions, samples etc., by pipette from one bottle to another, use a rubber bulb or other automatic pipetter, NOT THE MOUTH.

(ii) Use safety glasses for shielding against possible splashing.

(iii) Wear protective clothing (such as a lab coat, for example) to prevent damage to clothing.

3. Make sure that no air bubbles are trapped by tapping the side of the bottle near the shoulder with the stopper. Replace the stopper.
4. Mix thoroughly by turning upside down several times. Do this over a sink since there will be liquid in the seal around the stopper.
5. Allow to settle about half-way. Mix again by inverting and allow to settle a second time. (After addition of the manganous sulphate solution and the alkaline-iodide-azide solution, the samples can be left, if necessary, to complete other work.)

NOTE: When the alkaline-azide-iodide reagent is added, a dense precipitate will form. If this precipitate is pure white, there is no oxygen present; if the precipitate is amber-coloured, there is oxygen present.

6. Remove the stopper and add 2 ml of concentrated sulphuric acid above the liquid surface, letting the acid run down inside the neck of the bottle. Use another pipet for this reagent.
7. Replace stopper and mix by inverting. Do this over a sink. The amber solution of free iodine produced is not stable and should be titrated immediately.
8. Measure 100 ml of the solution in a 100 ml graduated cylinder. Transfer it to an Erlenmeyer Flask.
9. Fill the buret to the zero mark with 0.025N sodium thiosulphate.

10. Add sodium thiosulphate from the buret at a fast rate (steady stream) while mixing the contents of the flask by swirling. Slow down the rate of titrant addition as a pale yellow colour is reached.
11. When the solution is pale yellow, add about $\frac{1}{2}$ ml of starch solution (an eyedropper-full). The sample will turn blue and the titration is continued, adding the sodium thiosulphate dropwise until the solution is colourless. This is the END POINT.

NOTE: If the colour does not appear when the starch indicator is added, the titration has been carried too far and must be repeated. If the solution turns brownish black, the starch indicator has been added too early and the procedure must be repeated.

12. Record the amount of sodium thiosulphate solution used in ml.
13. When disposing of the sample (both the titrated portion and that remaining in the BOD bottle), leave the water running in the sink to thoroughly flush the acid down the drain.

Calculation

The concentration of dissolved oxygen in the original sample is equal to *twice* the number of ml of sodium thiosulphate used when 100 ml of solution are titrated.

e.g. The titration required 2.3 ml of sodium thiosulphate solution; therefore, the dissolved oxygen concentration was $2 \times 2.3 = 4.6$ mg/l.

THE HACH DO KIT

This method is essentially a Winkler dissolved oxygen determination with all chemicals supplied in kit form.

1. It is a small, completely self-contained kit.
2. It is easy to transport.
3. It is easy to use (see procedure).
4. It is a modification of the Sodium Azide modification of the Winkler Test.
5. The Hach DO Kit is suited for plant applications. All the chemicals are contained in small plastic pillows, with the exception of the titrating solution. This keeps them uncontaminated and they will last a long period of time. The titrating solution, which is phenylarsene oxide, is very stable. By avoiding contamination, and keeping it well stoppered, it will remain stable for an exceptionally long period of time.

NOTE: FOLLOW THE SAMPLING AND ANALYTICAL INSTRUCTIONS CAREFULLY TO PRODUCE RESULTS COMPARABLE TO THE WINKLER METHOD.

Procedure Using the Hach DO Kit

1. Fill the DO sample bottle with the water to be tested by allowing the water to overflow the bottle for 2 or 3 volumes. Be certain there are no air bubbles in the bottle.
2. Add the contents of one Dissolved Oxygen I Powder Pillow (Manganous Sulphate) and one Dissolved Oxygen II Powder Pillow (Alkaline Iodide-Azide). Stopper in a manner to keep out air. Shake to mix and allow the floc that is formed to settle half-way in the bottle.

3. Remove the stopper and add the contents of one Dissolved Oxygen III Powder Pillow (Dry Acid). Re-stopper and shake to mix. The floc will dissolve and a yellow colour will develop if oxygen is present. *This is the prepared sample.*
4. Fill the sample measuring tube level full with prepared sample and pour it into the 1 oz. titrating vial.
5. Using the dropper provided, add PAO Solution, swirling to mix, and counting each drop. The titrating end point is reached when the sample has turned colourless. Use starch indicator if available to obtain sharper end point. The mg/l Dissolved Oxygen is equal to the number of drops used.

NOTE: It is a bit tricky to stopper the DO sample bottle without getting an air bubble trapped in the bottle. To avoid the air bubble, tip the sample bottle slightly, and insert the stopper with a quick thrust. This will force the air bubbles out.

All the above directions are supplied with the kits and include a procedure for Low Range Dissolved Oxygen where each drop of PAO is equal to 0.2 mg/l.

PREPARATION OF REAGENTS

Copper Sulphate - Sulphamic Acid

1. Dissolved *approximately* 32 gm of technical grade sulphamic acid ($\text{NH}_3\text{SO}_2\text{OH}$) without heating in about 475 ml of tap or distilled water.
2. Dissolve 50 gm of technical grade copper sulphate crystals ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$) in about 400 ml of tap water.

3. Mix the two solutions.
4. Add *approximately* 25 ml of concentrated acetic acid.

Manganous Sulphate Solution

1. Weigh out about 480 gm of manganous sulphate ($\text{MnSO}_4 \cdot 4\text{H}_2\text{O}$).
2. Dissolve in 400 to 600 ml of distilled water.
3. Add distilled water to make up volume to 1 litre.

NOTE: Filtration of the solution as recommended in "Standard Methods" may be necessary if there is an oily film on top, or if there is evidence of insoluble black matter.

The solution, using reagent grade manganous sulphate, is a clear pink colour.

Alkaline Iodide-Azide Solution

1. Weigh about 500 gm of sodium hydroxide (or about 700 gm of potassium hydroxide).
2. Dissolve the sodium hydroxide in 500 to 600 ml of distilled water in a Pyrex beaker, cooling the solution in a water or ice bath.
3. Weigh about 150 gm of potassium iodide (KI) (or 135 gm of sodium iodide, NaI).
4. Dissolve the potassium iodide in about 200 to 300 ml of distilled water. When the sodium hydroxide solution is cool, add the potassium iodide solution to it slowly while mixing.
5. Dissolve about 10 gm of sodium azide (NaN_3) in 50 ml of distilled water. CAUTION: Sodium azide is unstable and in acidic solution could be explosive and also releases toxic fumes.
6. Add the sodium azide solution to the cooled alkaline iodide solution.
7. Dilute with distilled water to 1 litre.

Sulphuric Acid

Use concentrated reagent grade sulphuric acid. Handle it carefully because it is a strong acid. It will "burn" holes in cloth, especially cotton, and can cause severe irritation of the skin.

NOTE: ALWAYS ADD ACID TO WATER - NEVER WATER TO ACID.

Starch "Solution"

1. Make a thin paste of 3 gm of starch (soluble, potato, arrowroot, etc.) with a small amount of distilled water.
2. Pour into 500 ml of boiling distilled water.
3. Add 1.25 gm/l of salicylic acid for preservation.
4. Allow to cool and settle overnight.
5. Decant, saving the clear supernatant.

Sodium Thiosulphate Solution (0.025N)

NOTE: 0.025N Sodium Thiosulphate Solution may be purchased from some chemical supply houses, or prepared as follows:

1. Weigh out, as accurately as possible, 6.20 gm of sodium thiosulphate crystals ($\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$). Do not dry before weighing.
2. Dissolve in distilled water and make up to 1.00 litre with distilled water.
3. Add about 5 ml chloroform or about 0.4 grams of sodium hydroxide pellets as a preservative.

NOTE: If this solution is to be used for plant dissolved oxygen tests only, it will be sufficiently accurate. However, if it is to be used in BOD determinations, it should be standardized against 0.025N Potassium Dichromate (Reagent g). Because the sodium thiosulphate solution is unstable,

it should be replaced every month or standardized weekly if it is used for BOD's.

Potassium Dichromate Solution (0.025N)

NOTE: 0.025N Potassium Dichromate Solution may be purchased from some chemical supply houses, or prepared as follows:

1. Put about 5 gm of reagent grade potassium dichromate ($K_2Cr_2O_7$) in a 50 ml beaker or a weighing bottle.
2. Dry the potassium dichromate at $103^{\circ}C$ overnight in the oven.
3. Cool in desiccator.
4. Weigh out exactly 1.226 gm, transferring it to a 1 litre volumetric flask.
5. Dissolve in distilled water; make up to the 1 litre mark.
6. Transfer the solution to a reagent bottle for storage. No solutions should be stored in volumetric flasks.
7. This solution is stable and will not have to be replaced unless it becomes contaminated or is allowed to evaporate significantly.

SUBJECT:

SEWAGE TREATMENT
PROCESS CONTROL

TOPIC: 13

CHLORINE TESTING PROCEDURES
- DPD METHOD
- ORTHOTOLIDINE TEST
- AMPEROMETRIC

OBJECTIVES:

The trainee will be able to

1. Demonstrate and carry out the procedures for determining the chlorine residual using the DPD method with the Nesslerizer and Comparator.
2. Determine the chlorine residual of a given sample using the Orthotolidine Test.
3. Describe the principle of operation of the Amperometric Titrator and/or carry out chlorine analysis on such an instrument.

CHLORINE TESTING PROCEDURES

DPD METHOD

Principle of the Method

Research in chlorine chemistry has resulted in the development of a very simple procedure for the determination of total residual. With the new method differentiation between the combined forms of chlorine is also possible using the DPD indicator. The test is accurate and, when properly used, it can be an excellent aid in the control of chlorine residual at a wastewater treatment plant.

A good feature of the Lovibond Comparator method lies in its use of compressed tablets which are convenient to handle and more stable than the DPD solution. In a recent investigation by the Water Research Association, this method was judged the BEST COLORIMETRIC METHOD for the measurement of total residual chlorine in water.

Equipment and Reagents Required

1. DPD tablets for Comparator and Nesslerizer
Nos. 1 & 3 together for total chlorine residual, or No. 4 which replaces both Nos. 1 and 3.
2. Comparator with Standard Lovibond Discs
 - a) 3/40A disc covers the range 0.1 to 1.0 mg/l chlorine.
 - b) 3/40B disc covers the range 0.2 to 4.0 mg/l chlorine.

These discs require 13.5 mm cells or test tubes. A dulling screen must be used.

3. Nesslerizer with Disc

NDP covers the range 0.05 to 0.5 mg/l. This disc must be used with a dulling screen and 50 ml tubes.

Procedure - Total Chlorine Residual

1. Comparator

- a) Place a 13.5 mm cell or test tube containing sample only in the lefthand compartment, behind the colour standards of the disc.
- b) Rinse a similar cell with the sample, and fill the cell or tube up to the mark with it.
- c) Into this cell or tube drop one No. 1 and one No. 3 tablet (or one No. 4 tablet, which is No. 1 and No.3 combined).
- d) Allow tablets (or tablet) to disintegrate until effervescence ceases.
- e) *Mix rapidly* to dissolve the remains of the tablet.
- f) Place the cell in the righthand compartment of the Comparator.
- g) *After 2 minutes, match the cells by holding the Comparator facing a good source of diffused north daylight and revolve this disc until the correct standard is found. NEVER LOOK INTO THE SUN.*
- h) The figure shown in the indicator window represents mg/l of *total chlorine residual* present in the sample.

2. Nesslerizer

Follow exactly the same procedure for the Comparator, with the following exceptions:

- a) Use 50 ml instead of 10 ml.
- b) Use special Nesslerizer DPD tablets.

Note: *It must be emphasized that the readings obtained by means of the B.D.H. Lovibond Nesslerizer and disc are only accurate provided that Nesslerizer glass is used which conforms to the specification employed when the discs are calibrated; namely, that the 50 ml calibration mark shall fall at a height of 113 ± 3 mm, measured internally.*

ORTHOTOLIDINE TEST (OT)

General

The orthotolidine test (OT) is used to determine the presence of chlorine residuals. The wastewater is tested for total chlorine residual 15 minutes or longer after chlorination by adding the sample to the OT reagent in a glass tube or glass container. A yellow colour in the sample indicates the presence of a chlorine residual. The deeper the yellow, the greater the residual. The speed of colour development of combined residuals is increased with higher water temperatures, the desirable temperature of the sample being 20°C.

The OT method is an old one dating back to 1914, and is still in use in many plants. It has the disadvantages that -

the super-sensitivity of the chemical causes high intensity colour development so that a chlorine residual cannot be measured accurately above 1 ppm concentration.

The OT method is being replaced by the DPD and the Amperometric methods.

Procedure for Total Chlorine Residual

1. Pour the required amount of OT reagent into the Nessler tube, Colorimeter cell or other container.

Use:

- 0.5 ml OT reagent in 10 ml cell
 - 0.75 ml OT reagent in 15 ml cell
 - 5.0 ml OT reagent in 100 ml cell
- and similar ratios for other volumes.

Note: *OT reagent should not be kept longer than 6 months. It should be stored in amber-coloured bottles, kept out of direct sunlight and should not be subjected to high or low temperature. Fresh supplies of OT reagent may be obtained free of charge from the M.O.E. Laboratories.*

2. Adjust the temperature of sample to between 15°C and 24°C (quickly), using warm or cold water.
3. Add sample to the cell or tube up to the mark.
4. Mix solution.
5. About 5 minutes after maximum colour develops, a slight fading begins; therefore, samples containing combined chlorine should be read within 5 minutes and should, preferably, be allowed to develop colour in the dark.

AMPEROMETRIC TITRATION METHOD

General

The most accurate methods of measuring total chlorine residuals is through oxidation-reduction titration procedures. Such methods require the use of internal indicators or electro-metric devices employing a suitable electrode system to show when reactions are completed. Amperometric titrators employing rotating platinum electrodes have been developed for such purposes. (See Figure 11-1, page 11-5.)

Titration - Principle of Operation

Titration is a method used to determine the concentration of a substance in a solution. This is accomplished by adding the smallest amount of a reagent (of known concentration) required to cause a neutralizing effect, in reaction with a known volume of the test solution. A graduated vessel (or burette) is used to add the reagent to the known volume of test solution until the chemical reaction between the two is completed. The point of completion is indicated by either (a) adding an indicator dye and watching for a change in its odour or (b) stopping at a predetermined end point on a pH meter or microammeter.

A direct current potential is impressed across two nodal metal electrodes immersed in a measuring cell containing the sample of the solution to be tested. Any flow of current between the electrodes is directly proportional to the quantity of halogen (such as chlorine, bromine, or iodine) in the sample. The presence of a current is indicated on a microammeter at the top of the instrument.

A reagent (also called a titrant), phenylarsene oxide, is added in small doses to the sample, and reacts chemically with the chlorine present in the solution, thereby neutralizing a portion of the chlorine. As more titrant is added, more chlorine is "removed", causing the current flowing between the electrodes to diminish as indicated by the microammeter pointer moving down the scale. Finally, sufficient titrant is added to react with all the chlorine, and no further decrease in current is possible. This is called the *end point*.

The amount of chlorine residual present in the test solution is determined by noting the number of millilitres of titrant used to attain the end point. Then:

$$\text{mg/l of chlorine} = \frac{\text{mls of titrant that have been used}}{\text{mls of sample}}$$

Procedure

1. Switch on
Set the rocker switch to the TOTAL position.
2. Filling the Burette
Make sure the titrant (phenylarsene oxide solution) fills to the zero mark.
3. Titration of Total Chlorine Residual
 - a) Fill the solution jar with 200 ml of sample.
 - b) Add 1 ml Potassium Iodide Solution followed by 1 ml pH4 buffer solution IN THAT ORDER.
 - c) Fill the microburette with the titrant (phenylarsene oxide solution) to the zero mark.
 - d) Titrate by adding phenylarsene oxide solution and observe current changes on the microammeter. As long as addition of phenylarsene oxide produces a definite decrease in current, free chlorine residual is present.
 - e) The end point is just passed when a very small increment of phenylarsene oxide no longer causes a decrease in current.
 - f) The burette is then read and the last increment of titrating solution is subtracted from the reading to give a value representing the total chlorine residual.

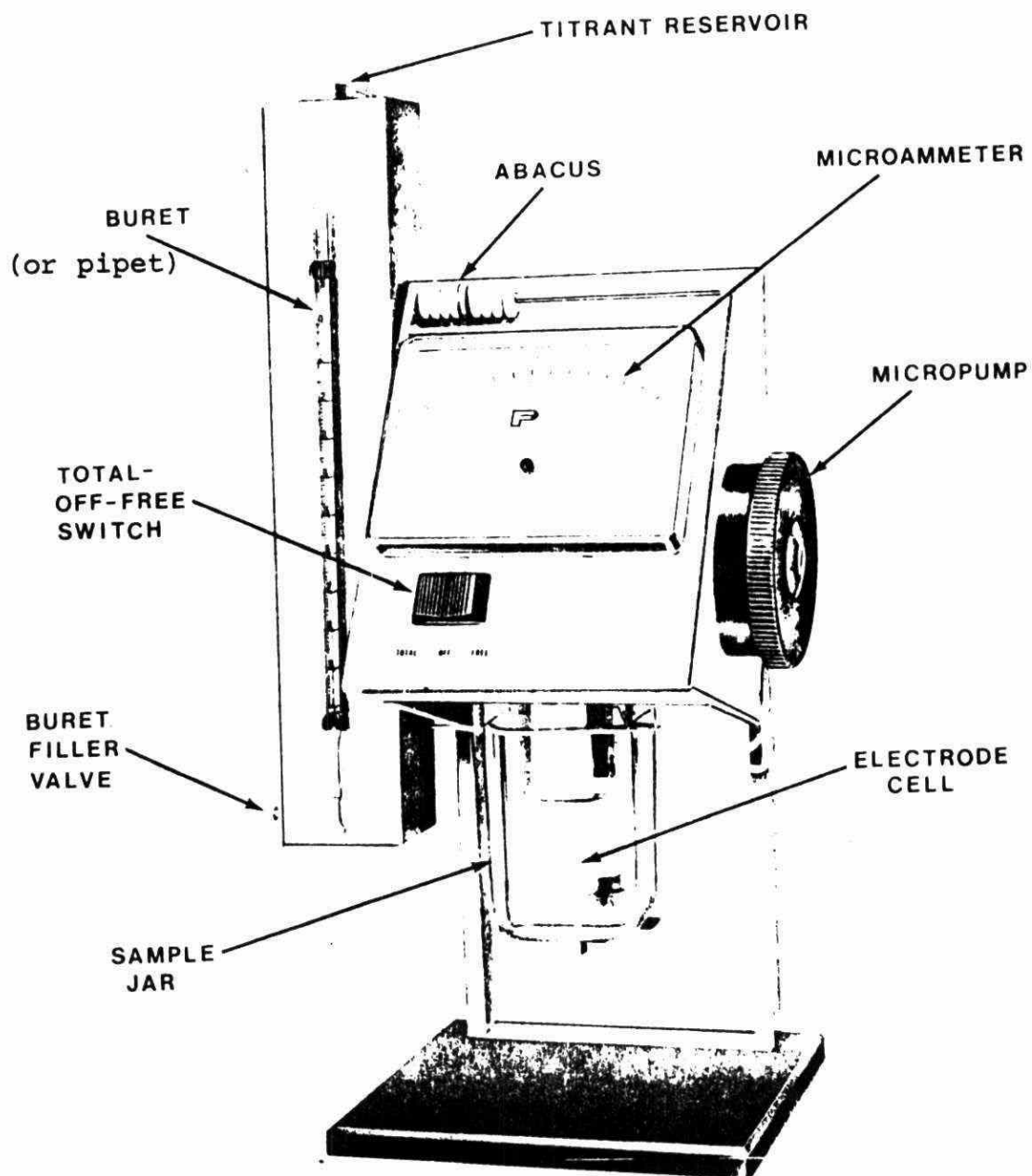


Fig. 13-1 Amperometric Titrator
(Courtesy Fischer & Porter)

GLOSSARY OF TERMS

The following definitions are intended only as aids in the study of this manual.

absorption -

The taking up of one substance into the body of another.

activated sludge -

Sludge floc produced in raw or settled wastewater by the growth of zooglycal bacteria and other organisms in the presence of dissolved oxygen and accumulated in sufficient concentration by returning floc previously formed.

adsorption -

- (1) The adherence of a gas, liquid, or dissolved material on the surface of a solid.
- (2) A change in concentration of gas or solute at the interface of a two-phase system. Should not be confused with absorption.

aeration -

- (1) The bringing about of intimate contact between air and a liquid by one or more of the following methods:
 - a. spraying the liquid in the air,
 - b. bubbling air through the liquid,
 - c. agitating the liquid to promote surface absorption of air.
- (2) The supplying of air to confined spaces under nappes, downstream from gates in conduits, etc. to relieve low pressures and to replenish air entrained and removed from such confined spaces by flowing water.
- (3) Relief of the effects of cavitation by admitting air to the section affected.

aerobic -

Requiring, or not destroyed by, the presence of free elemental oxygen.

algae -

Tiny plants, usually living in water and often green.

alkaline -

A condition which will raise the pH in water or wastewater higher than 7.

bacteria -

Single-celled microscopic plants living in soil, water, organic matter, or the bodies of plants and animals.

baffle -

A device to turn aside, check, or regulate flow.

barminutor -

Trade name for a shredding device.

bar screen -

A rack made of parallel bars for removing coarse materials in the wastewater passing between them.

BOD -

Biochemical Oxygen Demand. A measure of the oxygen used in decomposing organic matter.

bulking -

Bulking occurs in activated sludge plants when the sludge becomes too light and will not settle properly.

centrifuge -

A machine that separates solids from wastewater in a spinning motion.

chemical oxygen demand -

A measure of the oxygen-consuming capacity of inorganic and organic matter present in water or wastewater. It is expressed as the amount of oxygen consumed from a chemical oxidant in a specific test. It does not differentiate between stable and unstable organic matter and thus does not necessarily correlate with biochemical oxygen demand. Also known as OC and DOC, oxygen consumed and dichromate oxygen consumed, respectively.

chlorine demand -

The difference between the amount of chlorine added to a water or wastewater and the amount of chlorine residual left after a certain length of time.

clarifier -

A unit of which the primary purpose is to secure clarification. Usually applied to sedimentation tanks or basins.

coagulants -

In water and wastewater, chemicals used to thicken finely divided suspended solids into groups for easy removal.

coagulation -

In water and wastewater treatment, the destabilization and initial aggregation of colloidal and finely divided suspended matter by the addition of a floc-forming chemical or by biological processes.

colloidal -

Finely divided solids which will not settle but may be removed by coagulation or biochemical action or membrane filtration.

comminutor -

A shredding device used in pretreatment.

cross flight -

Wooden scraper for moving sludge and scum in a rectangular clarifier.

decomposition -

Generally aerobic processes that convert unstable materials into more stable forms by chemical or biological action. Waste treatment encourages decay in a controlled situation in order that the material may be disposed of in a stable form. When organic matter decays under anaerobic conditions (putrefaction), undesirable odours are produced. In aerobic processes, the odours are much less objectionable than those produced by anaerobic decomposition.

detention time -

The length of time that wastewater is held in a unit for treatment.

detritor -

Equipment used in pretreatment to remove heavy minerals such as grit, and other coarse debris carried in water and wastewater.

diffuser -

A device for distributing tiny air bubbles throughout a liquid, such as wastewater.

digestion -

The biological decomposition of organic matter to a more stable form.

dissolved oxygen -

Atmospheric oxygen dissolved in water or wastewater, usually abbreviated DO.

effluent -

In wastewater treatment, wastewater or other liquid, partially or completely treated or in its natural state, flowing out of a reservoir, basin, treatment plant, or industrial treatment plant, or part thereof.

elutriate -

To purify, separate, or remove by washing.

endogenous -

A diminished level of respiration in which materials previously stored by the cell are oxidized.

enzyme -

A protein that promotes a chemical reaction, enabling it to continue at body temperature.

filamentous bacteria -

These bacteria develop where carbohydrates are present and where there is low dissolved oxygen content. The result is bulking and poor settling. These organisms grow in a thread or filamentous form.

flights -

Wooden scrapers mounted on parallel chains to move sludge to a hopper at the end of a rectangular clarifier.

floc -

Small gelatinous masses formed in a liquid by the reaction of a coagulant added thereto, through biochemical processes, or by agglomeration.

flocculation -

The collection of coagulated suspended solids into a mass by gentle stirring.

flotation -

The raising of suspended matter to the surface of wastewater in a tank for removal by skimming.

fungi -

Small non-chlorophyll-bearing plants which lack roots, stems, or leaves, which occur (among other places) in water, wastewater, or wastewater effluents and grow best in the absence of light. Their decomposition after death may cause disagreeable tastes and odours in water; in some wastewater treatment processes they are helpful and in others they are detrimental.

Imhoff tank -

A wastewater treatment tank with two chambers for sedimentation and sludge digestion.

influent -

Water, wastewater, or other liquid flowing into a reservoir, basin, or treatment plant, or any unit thereof.

inorganic -

Chemical substances of mineral origin, or more correctly, not of basically carbon structure.

metabolize -

To perform the chemical changes in organic cells, providing energy for growth and activity.

microbes -

Microscopic organisms, especially pathogenic bacterium.

micro-organisms -

Minute organisms, either plant or animal, invisible or barely visible to the naked eye.

mixed liquor -

A mixture of activated sludge and organic matter undergoing treatment in the aeration tank.

nitrification -

- (1) The conversion of nitrogenous matter into nitrates by bacteria.
- (2) The treatment of a material with nitric acid.

nutrient -

Food for the growth of organisms.

organic -

Chemical substances of animal or vegetable origin, or more correctly, of basically carbon structure, comprising compounds consisting of hydrocarbons and their derivatives.

oxidation -

The act of combining with oxygen; any reaction which involves the loss of electrons from an atom.

oxygenation capacity -

In treatment processes, a measure of the ability of an aerator to supply oxygen to a liquid.

Parshall Flume -

A device used to measure liquid flow in a channel.

pH -

The measure of the acid/alkaline balance, expressed on a scale of 0 to 14, with 7 being neutral; 7 to 0 increasing acidity, and 7 to 14 increasing alkalinity.

preaeration -

A method of preparing wastewater for treatment by aeration to remove gases, add oxygen, float grease, etc.

protozoa -

Unicellular microscopic animals, protozoa consume bacteria, thus promoting the growth of new bacteria. They feed on the surface of biological floc and on dispersed bacteria, which results in a clear effluent. The presence of protozoa indicates that there is sufficient dissolved oxygen and a lack of toxic elements. There are two basic forms:

Free-swimming ciliate protozoa - Fine hairs allow these ciliates to swim rapidly. They have a high energy level and require a large quantity of organic food.

Stalked ciliate protozoa - Normally found in high-rate systems in equal numbers with the free-swimming ciliates, they attach themselves by their stalks to solid particles.

putrescible -

- (1) The relative tendency of organic matter to undergo decomposition in the absence of oxygen.
- (2) The susceptibility of wastewaters, effluent, or sludge to putrefaction.
- (3) In water or wastewater analysis, the stability of a polluted water or raw or partially treated wastewater.

retention time (or period) -

The theoretical time required to displace the contents of a tank or unit at a given rate of discharge (volume divided by rate of feed). Also called detention time.

rotifers -

Multicellular microscopic animals which feed on bacteria and protozoa, rotifers exist only in the presence of dissolved oxygen and are an indication of a high degree of treatment. They are normally found in extended aeration systems.

stabilize -

To convert to a form that resists change. Organic material is stabilized by bacteria which convert the material to gases and other relatively inert substances. Stabilized organic material generally will not give off obnoxious odours.

sedimentation -

Settling or clarification; the process of allowing solids in water and sewage to sink to the bottom for easy removal.

supernatant -

The liquid standing above a sediment or precipitate.

suspended solids -

- (1) Solids that either float on the surface of, or are in suspension in, water, wastewater, or other liquids, and which are largely removable by laboratory filtering.
- (2) The quantity of material removed from wastewater in a laboratory test, as prescribed in "Standard Methods for the Examination of Water and Wastewater" and referred to as non-filterable residue.

total solids -

The sum of dissolved and undissolved constituents in water or wastewater, usually stated in milligrams per litre.

turbidity -

A condition in water caused by suspended matter; murkiness.

volatile solids -

The quantity of solids in water, wastewater, or other liquids, lost on ignition of the dry solids at 550°C.

weir -

A dam or enclosure in water or wastewater used to raise the water level or change the direction of its flow; with notches or a crest, it measures the flow.